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Review and Annotated Bibliography

Fish and Wildlife Service

U.S. Department of the Interior

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EFFECTS OF CONTAMINATED SEDIMENT ON FISH AND WILDLIFE: REVIEW AND ANNOTATED BIBLIOGRAPHY

by

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PREFACE

This report is intended to provide a summary treatment of the effects of contaminated sediment. Through this introductory treatise, we hope to engender the necessary caution and concern which will urge a more complete understanding of the role of toxic chemicals in the biosphere.

Any questions or comments about or requests for this publication should be directed to:

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ACKNOWLEDGMENTS

It is difficult in many ways to pull together a bibliography such as this, since there is a certain amount of subjectivity involved in the selection of articles and in the emphasis which one gives to each. Nonetheless, the result is this review and compendium of the (mostly recent) literature. The bibliography is an outgrowth of interest generated in my capacity as an ecologist with the Florida Department of Environmental Regulation. It does not, however, reflect any official positions of that agency.

Helping to shape the final product, not only in terms of material to be included, but also in terms of format and general tone, were a number of people. Much credit should go to Lawrence Eaton, Florida State University Department of Oceanography, for his help in note-taking, winnowing of the literature, wading through voluminous computer searches, and retrieving library materials. In addition, Larry made many good suggestions regarding the abstracts. Thanks also to several editors, among them Pamela Ferris-Olson and Kathryn Lyster; to Anna Freed, Nanex Systems Corporation, for secretarial services; to Susan Frederickson for her word-processing assistance; and to several anonymous scientific reviewers who provided pertinent criticisms and suggestions. Finally, thanks to Ken Adams, the project officer, for his helpful guidance and editorial critiques. His patience and thoughtfulness were greatly appreciated.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

LC_{50}	the concentration of a solution of a toxic substance which is lethal to 50% of the test organisms at a specific time of observation (e.g., 96-hr LC_{50})
LD_{50}	the dose of a toxic substance which is lethal to 50% of the test organisms at a specific time of observation (e.g., 96-hr LD_{50})
mg	0.001 g (one-thousandth of a gram); a milligram
μg	0.000001 g (one-millionth of a gram); a microgram
pCi	1×10^{-12} Curie; a picocurie; a measure of radiation where a Curie is a unit of any radionuclide in which 3.7×10^{10} disintegrations occur per second
ppb	parts per billion (e.g., 1 μg/kg; 1 μl/l)
ppm	parts per million (e.g., 1 mg/kg; 1 mg/l)
TL_m	median tolerance limit; the concentration of a test material at which 50% of the test organisms survive for a given period of time (e.g., 96-hr TL_m); has been largely superseded in common usage by LC_{50}

SYMBOLS

Ac	actinium
Al	aluminum
Am	americium
Sb	antimony
Ar	argon
As	arsenic
At	astatine
Ba	barium
Bk	berkelium
Be	beryllium
Bi	bismuth
B	boron
Br	bromine
Cd	cadmium
Ca	calcium
Cf	californium
C	carbon
Ce	cerium
Cs	cesium
Cl	chlorine
Cr	chromium
Co	cobalt
Cb	columbium
Cu	copper
Cm	curium
Dy	dysprosium
Es	einsteinium
Er	erbium
Eu	europium
Fm	fermium
F	fluorine
Fr	francium
Gd	gadolinium
Ga	gallium
Ge	germanium
Au	gold
Hf	hafnium
He	helium
Ho	holmium
H	hydrogen
In	indium
I	iodine
Ir	iridium
Fe	iron
Kr	krypton
La	lanthanum
Lr	lawrencium
Pb	lead
Li	lithium
Lu	lutetium
Mg	magnesium
Mn	manganese
Md	mendelevium
Hg	mercury
Mo	molybdenum
Nd	neodymium
Ne	neon
Np	neptunium
Ni	nickel
Nb	niobium
N	nitrogen
No	nobelium
Os	osmium
O	oxygen
Pd	palladium
P	phosphorus
Pt	platinum
Pu	plutonium
Po	polonium
K	potassium
Pr	praseodymium
Pm	promethium
Pa	protactinium
Ra	radium
Rn	radon

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Re	rhenium	Sr	strontium	Ti	titanium
Rh	rhodium	S	sulfur	W	tungsten
Rb	rubidium	Ta	tantalum	U	uranium
Ru	ruthenium	Tc	technetium	V	vanadium
Sm	samarium	Te	tellurium	W	wolfram
Sc	scandium	Tb	terbium	Xe	xenon
Se	selenium	Tl	thallium	Yb	ytterbium
Si	silicon	Th	thorium	Y	yttrium
Ag	silver	Tm	thulium	Zn	zinc
Na	sodium	Sn	tin	Zr	zirconium

CHAPTER 1
INTRODUCTION

Numerous authors have reviewed the subject of the effects of contaminants on organisms. The toxicological literature is replete with studies of the effects of chemical constituents in the water column on the biota. Further, there are many papers about the physical effects of sediments: gill clogging, decrease of light, and burying. There are few reviews, however, which tie a chemical constituent of the sediment to the biota with which it comes in contact. Several reviews have concentrated on some aspects, such as metals and other contaminants in the United States (Dredged Material Research Program, U.S. Army Corps of Engineers).

Therefore, to address the need for an annotated bibliography which deals with the effects of polluted sediment on the biota, the published literature was perused. Papers which concern both sediment and biota were sought via extensive literature searches, interlibrary loans, and computer searches using key words and phrases. For the latter, several international services were utilized which resulted in several thousand titles and abstracts which appeared to be promising. Final selection from all sources resulted in over 150 papers which have been abstracted to reflect the present concerns.

The purpose of this review is to summarize, from the selected annotated bibliography which follows, the effects of contaminated sediment on the biota. It is intended to be specific to avoid duplication of toxicological literature reviews. Sometimes, however, the lines between the kinds of effects we would want to include and those best left to other reviews are difficult to distinguish. Generally, unless there is some explicit or strongly implied association with the sediment, the paper was not included. Topics of eutrophication and nutrient enrichment have not been included, since neither is considered to be directly harmful to organisms. Nor have we consciously included literature which deals strictly with the chemical aspects of contaminated sediment. The literature concerning the latter is voluminous. If, however, a paper deals with rates of reactions or transport or transformations in the context of the biota associated with the sediment, then it has been included.

"Gray" literature, such as Government reports, Federal, State, and local agency reports, and M.S. and Ph.D. theses are reported only incidentally, as no systematic approach was followed to gather this information. Some of the foreign literature may be cited on the basis of only translated abstracts if there were no available English translations. Literature cited in this paper is referenced via the Abstracts section which follows. Because one of the main interests in a document such as this is the organismal response to a pollutant(s), the following subjects will be discussed, where applicable: (1) availability to organisms, (2) biological effects, (3) types of plants and animals affected and during which life stages, if known, (4) bioaccumulation,

(5) food web influences, and (6) major geographical locations of contaminated sediment. Pollutant categories chosen for discussion are: heavy metals, hydrocarbons, pesticides and other organics, and radionuclides.

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CHAPTER 2
HEAVY METALS

2.1 AVAILABILITY

The availability of sediment-associated heavy metals to the biota depends upon the physical and chemical nature of the sediment and water at the locale in question. Chen et al. (1976), studying the potential for migration of chemical constituents during open water disposal of sediments, determined that there is a "sudden release" of metals to seawater, especially during the first hour. The subsequent removal from solution in the laboratory was either gradual, under reducing conditions, or rapid, under oxidizing conditions. Other laboratory tests have also determined that metals over the long term are released slowly (Brannon et al. 1978). In some cases after four or more months, equilibrium conditions between water and sediment were such that there was a net movement of metals from water to sediment (e.g., Mn). Particle size, pH, the redox potential, presence of chelating agents, and metal content of the substrate affect the availability of metals to plants and animals. Blom et al. (1976), working with sediment from the Great Lakes and from New York Harbor, determined that there was no evidence that the total sediment organic carbon content directly controlled the release of metals, but that the chemistry of dredged material was complex and "poorly understood." Pesch and Morgan (1978) consider that particle size is of extreme importance when trying to determine the toxicity of metals to the infauna. They found that the presence of sand (vs. no substrate) will increase the time required to reach the LC_{50} values for Neanthes arenaceodentata in both short- and long-term (up to 28 days) experiments. In another experiment with copper toxicity, Pesch (1979) speculated that mud (as opposed to sand) as sediment probably adsorbed more Cu and, therefore, less of the metal was available to the organisms. She stated that sediment affects water-mediated toxicity of metals in two ways: (1) it causes time delay (i.e., compared to the absence of sediment), and (2) it actually lowers the exposure concentration by binding to the pollutant, thus tying it up. This may be a moot point when considering deposit feeders, however.

The pH influences the release of metals from sediment and, therefore, influences the uptake of the metals by plants (Gambrell et al. 1977). For example, significantly greater amounts of cadmium were released at low pH and under oxidizing conditions than under reducing conditions. Other metals (e.g., Cu) showed little variation in uptake with either variations in pH or redox potential (Gambrell et al. 1977). Similar pH and redox relationships have been found for other metals (Chen et al. 1976; Canter et al. 1977; Gambrell et al. 1977; Brannon et al. 1978; Chen et al. 1978; Gambrell et al. 1980). Ichikuni (1979) found that divalent Mn was released from sediment under reducing conditions and was taken up by prince feather (Polygonum orientale) leaves in a Japanese river.

Just as the type of sediment present (e.g., highly organic vs. inorganic; silts and clays vs. sand) will affect the "holding power" of the sediment to

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the metals (the least organic, most sandy substrates adsorb the least amounts of metals), the actual amounts of metals are also important in the availability of metals to organisms. For example, Lee et al. (1978), in developing "prediction equations" for metal uptake, found that metal uptake by marsh plants in general was about the same in disposal sites as in "natural" marsh areas. However, in a few locations with high metallic content, plants took up greater amounts of metals. Neff et al. (1978) discussed the availability of sediment metals to invertebrates from contaminated sediments in the Texas City and Corpus Christi ship canals and in Ashtabula (Ohio) Harbor. Of the 136 sediment-organism combinations tested, about 26 demonstrated significant positive correlation between exposure to sediment and heavy metal concentrations in the animals (Neanthes arenaceodentata, Rangia cuneata, Paleomonetes pugio, Tubifex sp. and Paleomonetes kadiakensis). The positive correlations varied, of course, depending upon the metal in question and the species of animal (e.g., 30 correlation for Pb in Neanthes). Ito (1981) found a more positive correlation between zinc in the guts of barnacles and substrate than between the guts and the water column. However, there is little evidence to suggest that any definable relationship exists between sediment concentration and bioavailability of a metal.

2.2 BIOACCUMULATION

The ability of plants and animals to take up and concentrate metals from the substrate so that tissue levels exceed ambient substrate concentrations has interested many researchers. Hydroponic laboratory experiments on various species of marsh plants showed that Spartina alterniflora, S. patens, and Cyperus esculentus had more potential than others studied (Scirpus robustus, Scirpus validus, Triglochin maritima, and Spartina foliosa) to take up Zn, Cd, and Ni (Lee et al. 1976). Pb and Cr accumulated in the roots of all species, but little translocated into leaves and stems. In other laboratory experiments, Gambrell et al. (1977) and Gambrell et al. (1980) determined that Spartina alterniflora and S. cynosuroides took up greater amounts of Cd at low pH under oxidizing conditions, while Distichlis spicata excelled at Cd uptake under slightly alkaline conditions. In a Japanese study, vegetational abundance in a copper polluted mining area was correlated not so much with copper, but rather with other edaphic factors, such as soil pH and hardness of the water (Abe and Kanda 1981). Bioaccumulation experiments on estuarine shrimps and clams (Paleomonetes spp. and Rangia cuneata) indicated that salinity was a controlling factor in the uptake of metals by Rangia (Neff et al. 1978). The authors postulated that Rangia may excrete metals at low salinities to maintain osmotic balance. Pentreath (1976a) studied the accumulation of mercury by the plaice, Pleuronectes platessa, which were force-fed pellets of radioactively labeled Hg. The results were variable, indicating possibly internal individual rates of distribution. However, the retention of mercury, particularly methylmercury, over time correlates well with known data on the mercury content of plaice caught in polluted nearshore waters. Likewise, feeding Hg capsules to the ray, Raja clavata, also resulted in much greater retention of the methylated forms of the metal, most of which is accumulated in muscle tissue (Pentreath 1976b).

Laboratory experiments by Tatem (1980) using polychaetes, amphipods, and mysid shrimp and Hg-contaminated sediment from the Houston Ship Canal, showed that the mysids (Mysidopsis bahia) died readily whereas the other groups were not significantly affected. The author surmised that this may be because of the epibenthic nature of the mysids which places them in contact with the sediment-water interface where Hg exchanges are most apt to take place. Laboratory experiments on sediment-associated methylmercury determined that the Red Sea bream (*Chrysophrys majior*) accumulated more methylmercury from the water column than from the sediment (Fujiki 1980a).

Several field studies have considered the bioaccumulation of metals from sediments. Among the most studied problems, possibly because of Minamata Disease, is mercury (Hg) accumulation. For example, Sheffy (1978) collected the bottom-feeding crayfish, *Oronectes virilis*, from the Wisconsin River. The concentration of Hg in the abdominal muscle tissue was highly correlated with sediment concentrations downstream from industrial sources. This crayfish data corresponded well with existing fish data from the same river (Sheffy 1978). Moore and Sutherland (1980) determined that Hg was still leaching from mine tailings in the sediment in a Canadian lake years after the cessation of mining operations. The leaching caused contamination in lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), and whitefish (*Coregonus clupeaformis*) probably through methylation of the sediment and then by transfer through the food web. In another paper, Moore et al. (1979) discussed the increase in benthic faunal diversity downcurrent from a goldmine in a Canadian subarctic lake. Teeny and Hall (1977) tested the influence of dumping sediment contaminated with mercury and cobalt in proximity to organisms (three species of shrimp, a sea cucumber, a mussel and a fish, the English sole) which were held in cages. The shrimps (Alaska pink, spot, and Oregon pink) and mussels used in the tests had no significant difference in tissue concentration before and after the sediment disposal, though the period of "after" varied among the animals tested (e.g., 3 days for the spot shrimp, 1 to 3 weeks for the mussels, 2 weeks for English sole, 2 to 39 weeks for Oregon pink shrimp).

Methylation of mercury is the most worrisome complication of mercury in the environment because of the potential for Minamata Disease in man. Accumulation of methylmercury by detritivores through ingestion of bottom material and subsequent ingestion of these by members higher in the trophic web resulted in the tragedy at Minamata Bay, Japan. Ishikawa and Ikegaki (1980) have summarized the Minamata Bay problem and the clean-up operations which will result in the eventual containment of the most contaminated sediment (i.e., >25 mg Hg/liter of sludge). Data collected in Minamata Bay between 1959-1972 indicated that levels of Hg in fish and shellfish decreased during that period, probably as a result of cessation of input of mercury used as a catalyst by a vinyl chloride/acetaldehyde chemical plant (Fujiki 1980b).

In addition to data from Minamata Bay, other studies have connected mercury with possible biological contamination. Dredging was initiated in Tokushima Bay, Japan, in order to reduce the amount of Hg in the sediment from a caustic soda factory (via mercury electrolysis) and which had shown up in high concentrations in fish and shellfish (Nakanishi and Ukita 1977). Also, Sato and Minokawa (1978) found that all rock trout examined in Kamaishi Bay, Japan, were contaminated with Hg, probably from sediment contaminated with 11-22 ppm Hg. Tuncel et al. (1980) measured mercury in sediments and organisms off the Turkish Mediterranean coast and demonstrated that the low values in both sediments and animals, with the exception of the polluted harbor of Mersin, were indicative of the relatively unpolluted waters of the eastern Mediterranean. The Hg content of biota off Hawaii was the subject of research by Klemmer (1976). There the highest concentrations of Hg in animal tissues occurred in those animals which feed just above the sediment-water interface. Hildebrand et al. (1980) studied fish and invertebrates upstream and downstream from a chloralkali plant to determine the relationship between Hg levels in the animals and the amounts in the water column and sediment. The benthos obtained most of the Hg from the sediment in the form of methylmercury (91.7 of the total Hg), which is soluble in water, and the fish obtained most of their Hg from the benthos. The mercury level in fish tissue remained above the FDA action level of 1.0 g/g for a downstream distance of over 21 km (13 mi) in the rock bass and over 69 km (43 mi) in the hogsucker. A study of mercury contamination in Canada by the Ottawa River Project Group (1979) determined that the mercury-containing slimicide used by a pulp mill was indeed adsorbed by the sediment and taken up by animals downstream. Desorption of Hg from the sediment to the water column is apparently an ongoing process; 17 of the metal is in the methylated form, which may be the form ingested by fish in a 4.8 km (3 mi) stretch of the Ottawa River. Elevated mercury levels (up to 50 ppm) were found in mussels near a mining region in the Adriatic Sea (Kosta et al. 1978). It was not stated how long the mining had been going on or if it had ceased.

Mercury contamination has been widely studied, but other metals are also of concern. A number of studies have examined heavy metals in general and their effects on the biota. A worldwide overview of certain heavy metals, such as Hg, Cd, and Zn, was presented by Foerstner (1980), in which he cited work regarding the bioaccumulation of metals from sediments. In particular, he cited Tokyo Bay, Hong Kong Harbor, Kaosiung Harbor (Taiwan), the New York Bight, Baltimore Harbor, Liverpool Bay, The Thames Estuary, and the German Bight, among others, as being heavily contaminated. Murphy (1981) cited documents which deal with worldwide heavy metal bioaccumulation. Frazier (1973) reviewed the status of knowledge through 1972 of the chemical and biological cycling of metals in the Chesapeake Bay. He addressed the following questions. Will thermal addition to bay waters increase the desorption of metals from the sediment? Will engineering projects which alter flow or salinity also alter the physical and chemical cycling of metals? He concluded that the available data were insufficient to answer those questions or to predict the effects of further metal contamination on estuarine biota. In another paper Frazier (1976) described his experiments with the American oyster, Crassostrea virginica, in metal-polluted vs. non-polluted areas of the Chesapeake Bay, finding, among other things, that shells were thinner at the metal-contaminated site and that levels of Cu in tissues were seven times that of the controls.

Engler's (1979) review paper on bioaccumulation of toxic substances from dredged sediment by fish and benthic organisms points out, as a number of papers do (Leland et al. 1978; Laube et al. 1979) that accumulation rates for metals vary over a wide range of parameters, including type of organism, exposure time and concentration, salinity, and temperature. Chapman et al. (1979) pointed out that oligochaetes appear to be particularly resistant to heavy metal pollution. They suspect some unknown mechanism by which internal metal levels are regulated by the animal. There is a depuration gradient in which Zn is the most easily depurated, followed by Hg, Cu, Pb, Ni, Cd, As, and, finally, Se, which is apparently not depurated (Engler 1979). Kosta et al. (1978), working on metals in marine organisms, waters, and sediments of the northern Adriatic Sea, determined that biomagnification is evident with Hg and Se in sharks, though high concentrations of metals in lower trophic levels were found only near a mining region. Jones and Ellis (1976) found an inverse correlation between the amount of mine tailings and population parameters of a polychaete, Ammotrypane aulogaster, in a Canadian estuary. The paper does not indicate the type of tailings involved, however. Also, Levings and McDaniel (1975) found that mine tailings and Kraft effluent caused benthic faunal damage on a Canadian beach.

Benthic organisms in the Kennebec River, Maine, were more affected by metal-polluted sediment than the fish (Friant 1979). Friant concluded that, since the mollusks, in particular, appear to accumulate metals they might be useful as indicator organisms. Shells and edible parts of short-necked clams in Tokyo Bay showed weak positive correlations with amounts of arsenic and copper in the substrate (Horii et al. 1980; Yasuno et al. 1980). Tietjen (1979) studied an area in Long Island Sound to determine if metal-contaminated sediment influenced nematode populations compared to an uncontaminated control area. No differences in nematode diversity were found which could be attributed to metallic (or organic carbon) content. A later paper (Tietjen 1980) refined this approach and looked at not only diversity indices and density, but also at species composition. This time, he noted a shift in species dominance, with low abundance of members of the Chromadoridae and Desmadoridae and dominance by the Comesomatidae in silty and/or high metal areas. In another study, sediment from Baltimore Harbor, heavily contaminated with metals (Pb, Cr, Zn, Cu, As), was used in laboratory bioassays with the mummichog, *Fundulus heteroclitus*, the spot, *Leiosthomus xanthurus*, and the softshelled clam, *Mya arenaria* (Tsai et al. 1979). The 24- and 48-hr TL_m values increased with sediment concentration and were species-specific. Sims and Presley (1976) determined that in the relatively unpolluted San Antonio Bay the fauna are also relatively uncontaminated with heavy metals despite about 50 years of sediment disturbances via dredging. Hunter et al. (1981) found that arsenic (As) was bioaccumulated by fish in an Oklahoma-Texas lake, but that the highest concentrations (up to 34 μg/g wet wt) were planktivores.

Several papers by Bryan and Hummerstone (1971, 1973, 1978) concerned sediment metals and benthic organisms in British estuaries. Concentrations of copper in the polychaete, *Nereis diversicolor*, were roughly proportional to those in the sediment, particularly where mining had occurred. Animals containing large amounts of copper survived in polluted areas because they developed a tolerance to its toxic effects (Bryan and Hummerstone 1971). Further, the concentration of zinc in solution influences the uptake of Cd from the sediment; Zn uptake is regulated by the worm, but Cd is influenced by its concentration in the sediment (Bryan and Hummerstone 1973). For the bivalve, *Scrobicularia plana*, in estuaries, work has shown that this common clam is a good accumulator of metals and, therefore, reflects changes in their bioavailability (Bryan and Hummerstone 1978; Bryan and Uysal 1978). A mussel (*Mytilus edulis*) and a clam (*Macoma balthica*) have also been shown to accumulate metals, particularly where chelating agents are present in the substrate (McGreer 1979; McGreer et al. 1980). Simply because bivalves accumulate metals, however, a biological or ecological effect does not necessarily follow. For example, though *Mya arenaria* in some parts of San Francisco Bay had elevated levels of metals, research on other organisms and other factors indicated that there is little correlation between metals and present-day San Francisco Bay problems (Bradford and Luoma 1980). Rather, constricted waterflow and siltation were thought to be the responsible agents. In Japan, Ito et al. (1981) were not able to determine specific indicator organisms for metal pollution in rivers.

Heavy metals in deposited sewage sludge is a special type of sediment contamination since sludge spreading is usually undertaken by municipalities on an experimental basis. Several recent research reports resulting from these experiments indicate that marsh plants take up sewage sludge metals. For example, in experimental saltmarsh plots with added sludge fertilizer, cadmium was found to be retained by sediment in greater amounts at low dosages than at higher dosages; and, though lead remained mainly in surface sediment, about 6-8% was taken up by marsh grass (Banus et al. 1979). In experimental tanks containing sand and *Thalassia testudinum* (turtle grass), sludge placed on top of the sand would leach into the water (Montgomery and Price 1979). Metals would enter the leaves of *Thalassia* as well as invertebrate fauna living among the leaves. Montgomery and Price concluded that it is unwise to place sludge in a turtlegrass or mangrove system or any other coastal marine area. Giblin et al. (1980), in studying the potential of salt marshes to act as waste treatment systems, found that *Spartina* spp. had elevated levels of several metals (Cd, Cr, Cu, and Zn), especially in the high marsh, which is less frequently inundated by the tide. Further, the mussel, *Modiolus demissus*, which is associated with the marsh, had significantly elevated levels of Cd, Cr, and Cu. Fiddler crabs, *Uca pugnax*, had significantly higher levels of Cd, Cu, and Mn.

Metal can bioaccumulate in plants growing in and around settling ponds used for coal ash retention. Cherry and Guthrie (1979) determined that broom sedge and nut grass growing in the sediment as well as duckweed growing on the water, bioaccumulated Hg and Zn above sediment levels.

The biota in roadside-associated streams can pick up significantly higher levels of metals than in areas of streams away from roads and streets (Van Hassel et al. 1980). Concentrations of Pb, Ni, and Zn in sediment in waterways bordering roads were highly correlated with traffic density. Tissue concentrations in benthic insects from these waters were similar to insects from contaminated waters. However, trophic level magnification was not evident. Flatau and Aubert (1979) found that bioconcentration from Cd-contaminated sediment decreased up the trophic levels, from phytoplankton to carnivorous fish. Finally, there are some who believe that the accumulation of metals in one trophic level may directly reflect lower trophic levels. For example, Jernelov and Lann (1971), working in Swedish lakes and streams, found that the accumulation of mercury through a food chain causes a concentration in the predator which is the same as the prey. To that level, they then accumulate more Hg from the water.

2.3 SUMMARY

1. Heavy metals are bioaccumulated from the sediment by benthic detrivores and omnivores as well as by plants. A number of factors such as pH, chelating agents, form of the metal, and species of animal or plant will influence the amounts of uptake. Statements concerning the extent of uptake from a given contaminated sediment, therefore, are in the form of generalities.

2. More work is needed on mechanisms of internal regulation, depuration of, and tolerance to heavy metals which are exhibited by some groups (e.g., clams, oligochaetes).

3. Information is needed on the extent of biomagnification of metals to higher trophic levels and the extent to which the water column also contributes to tissue concentrations.

CHAPTER 3
PETROLEUM HYDROCARBONS

3.1 AVAILABILITY

Chemical and physical processes affect petroleum hydrocarbons differently than metals, since petroleum hydrocarbons are generally long-chain molecules which can and do undergo breakdown in the environment as a result of weathering (exposure to water, oxygen, and sunlight). Though oils, as they will be synonymously referred to here, also adsorb to the sediment, they continue to break down for years in aquatic environments. Their breakdown is influenced by weathering (sunlight, wave action, oxidation). It is the lighter aromatic and short-chain compounds, however, which are the most toxic and which also are the most volatile. Hence, they are generally not long-term sediment compounds (Michael 1977; Murakami et al. 1980). In test plots, fresh crudes can take longer to disappear than weathered oil (Bender et al. 1980). However, Burns and Teal (1979) reported the persistence of aromatics and naphthalenes in Falmouth, Massachusetts sediments 8 years after a spill of number 2 fuel oil. This persistence has prevented total recolonization of the sediment (Burns and Teal 1979; Sanders et al. 1980). Also, in arctic climates, lighter fractions remain longer in the sediment than in temperate or tropical climates because of slower reaction rates (Atlas et al. 1978).

Studies of the biota which were subjected to a large oil spill (Bunker C) in Chedabucto Bay, Nova Scotia, found that in that cold climate, re-oiling of the area occurred every summer as the skin of the subsurface oil would soften under the influence of warm temperatures (Thomas 1973). Regarding that same spill in Chedabucto Bay, Scarratt and Zitko (1972) reported that subtidal animals were little affected and that there was little evidence of biomagnification. In a follow-up study, Thomas (1977) found that the re-oiling caused damage to Spartina which required 2 years to begin to recover. Recovery of faunal biomass abundance was still slow for a number of years after the spill (Thomas 1978). Physical effects on benthos include smothering, abrasion, and removal and alteration of substrates. Oil stranded on the shore breaks down more quickly by physical means than sunken mats of oil (Michael 1977). Giere (1979) points out, however, that the coarser the sediment, the faster and deeper oil is incorporated into it; hence, it is driven into deep, low oxygen layers where breakdown is slower.

If an area which is affected by an oil spill is not only coarse in sediment, but is also a very high energy area, the sediments stand little chance of permanent oiling. This apparently is the case off the coast of Chile, where oil went ashore from a spill, but little observable long-term biological damage was done (Baker et al. 1976).

DiSalvo et al. (1977) surveyed the content, levels, fate, and effects of oil and grease in sediments. They also performed experiments using chronically oil-contaminated sediments from areas such as New York Harbor (8,755 μg/g sediment), Duwamish River (1,224-2,301 μg/g), and Oakland Bay (748 μg/g). The clams and crabs utilized in their experiments showed oil uptake only in the New York Harbor sediment, which had the highest oil and grease concentrations of any tested. In Oregon thoroughly mixed oil and sediment set out in experimental trays in the intertidal zone contained 73% of the original concentration after 9 months, whereas surface-oiled sediment trays retained only 12-18% of the original concentration after only 100 days, indicating the importance of weathering processes (Anderson et al. 1978). There is evidence that for short periods high petroleum hydrocarbon levels in sediment are not necessarily toxic to the biota. For example, Anderson et al. (1977) subjected peanut worms, *Phascolosoma agassizii*, to high concentrations of naphthalenes and alkylnaphthalenes from Prudhoe Bay oil mixed with sediment (475-756 ppm), but after 2 weeks of exposure survival was still above 90%. However, it may be, as Lyles (1979) has determined for a polychaete, *Arenicola marina*, that naphthalenes in sediments are taken up less readily than naphthalenes in the water column. Both Anderson et al. (1977) and Lyles (1979) found depuration of naphthalenes by the experimental subjects within 24 hours to 2 weeks after transfer to clean water.

3.2 BIOACCUMULATION

The literature on the uptake and bioaccumulation of petroleum hydrocarbons from sediment reflects the complex nature of petroleums. Gilfillan and Vandermeulen (1978) studied two groups of clams (*Mya arenaria*) in Chedabucto Bay, Nova Scotia, one group of which had been oiled with Bunker C. The oiled group showed fewer numbers, fewer mature adults, lower shell growth rate and a 1 to 2 year lag in tissue growth. Oil was still found 5 cm below the sediment surface years after it had been flushed from the upper layers; thus, older clams, which must bury deeply, still suffered stress from the oil while new spat and juveniles, which settled on the substrate surface, were apparently not subjected to that stress (Gilfillan and Vandermeulen 1978). In another study dealing with arctic animals and oil-contaminated sediment, Percy (1977) found that the arctic temperatures delayed oil degradation and that the experimental animals (in this case, several species of amphipods) were unable to reject sediment contaminated with oil above a certain concentration. Experimentally oiled plots of *Spartina alterniflora* can withstand a large amount of oil without a decrease in above ground biomass, but new or growing blades can be affected (DeLaune et al. 1979). This appears to confirm observations by Thomas (1973, 1977) that re-oiling of *Spartina* caused damage to the plant. Such damage, however, may not be permanent to plants such as *Spartina*, which have large underground vegetation systems from which new growth can occur. Dicks (1976) cites a case in which the *Spartina* marsh revegetated after effluent oil from a refinery was stopped, even though the sediment had been heavily oiled. In the seagrass community in the vicinity of the *Amoco Cadiz* oil spill near Roscoff, France, it was found that direct effects on eelgrass were only temporary and that new leaf production proceeded normally (Jacobs 1980). The animals associated with the grasses, however, fared badly, with almost total disappearance of the crustaceans and echinoderms. Within a year, however, they returned to prespill levels, but amphipods and most families of polychaetes had not. Woodin et al. (1972) reported invertebrate larval recruitment within 6 months after an intertidal spill of number 2 diesel oil.

Lyles (1979) found that uptake of naphthalenes occurred in *Arenicola marina* mainly in the stomach wall and the esophageal glands and that most of the uptake was from the water column. In another naphthalene experiment, Taylor and Karinen (1977) found that clams, *Macoma balthica*, moved to the surface of oil-treated sediment, responding in direct proportion to the concentration. A naphthalene concentration of 0.67 g of oil/cm^3 of sediment was necessary to move 50% of the clams to the surface in a day. They pointed out that, though the oil did not kill the clams in large numbers, forced movement to the surface in the natural environment might be tantamount to death because of the increased risk of predation. Shallow clam burial in oiled sediment was also observed by Pearson et al. (1981), who made the observation that changes in rates of predation due to contaminated sediment may have as much validity in the reduction of benthic populations as the toxic effects of a pollutant itself. Soft-shelled clams, *Mya arenaria*, in an oiled sediment are more likely to suffer neoplasms than those animals in unoiled sediment (Yevich and Barszcz 1977). There is also evidence (Roesijadi et al. 1978) that deposit feeders accumulate more oil than suspension feeders. At least this was the case with experimental sediment plots containing Prudhoe Bay crude oil and the deposit feeding clam (*Macoma inquinata*) and worm (*Phascolosoma agassizii*) as opposed to the suspension feeding clam (*Protothaca staminea*). In a review paper, Lee (1977) cites accumulation and depuration rates of oil in a number of marine organisms and indicates that some polychaetes, such as *Capitella capitata*, have enzymes which are able to metabolize hydrocarbons. McCain et al. (1978) suggested that in the sole, *Parophrys vetulus*, depuration is due to activation of an aryl hydrocarbon hydroxylase system during initial exposure to oil.

The general ecological effects of oiled sediment, some of which have been mentioned, are numerous. Rejection efficiency of sediments by corals is the same for oiled as well as for clean sand among West Indian corals; nor was there evidence of absorption of oil or ingestion of oil by the corals tested (Bak and Elgershuizen 1976). An article by Thompson et al. (1977) suggests that scarlet prawns were actually attracted to a benthic oil deposit off the coast of Aruba in the Dutch West Indies via release of a chemical from bacterial degradation of the oil. While this active attraction is not one of the usual reported reactions to oil, there are reported cases of at least passive resistance to oil toxicants, as earlier noted with worms and naphthalene (Anderson et al. 1977; Lyles 1979). Bacterial degradation of sediment-bound hydrocarbons may provide food for benthic infauna, as determined by Davis and Spies (1980) at a natural petroleum seep where the infaunal community was essentially the same at the oiled and non-oiled sites. Further, Bender et al. (1974), in their field and laboratory studies on a spill in the lower York River, Virginia, found that the molluskan assemblage exhibited a general resistance to oil toxicity. In fact, it appears to be a general phenomenon among estuarine and freshwater animals that they can withstand very high hydrocarbon levels for long periods without much uptake (Engler 1979). Boucher (1980) indicated that oligochaetes, polychaetes, and turbellarians in the *Amoco Cadiz* spill were generally resistant to oil pollution, while nematodes and other meiofauna (harpacticoid copepods and ostracods) were somewhat more sensitive. Barton and Wallace (1979) found that a mining oil sludge spill did not significantly reduce oligochaete and chironomid populations.

On the contrary, *Uca pugnax*, the fiddler crab, suffered for 7 years after an oil spill at West Falmouth, Massachusetts, exhibiting juvenile abnormalities and lower populations in the most heavily oiled (up to 6,000 ppm, originally) areas (Krebs and Burns 1977). In fact, the contamination at the Falmouth site was so great that no repopulation was observed in affected areas even 9 months after the spill (Murphy 1971). The *Amoco Cadiz* spill off the coast of France decimated the crustacean meiofauna and there are indications that residual oil in the sediment may have had a long-term effect on nematodes (Boucher 1980). Except for turbellarians, initial mortality in a spill off the coast of northern Spain included all of the meiofauna, including most nematodes (Giere 1979). Recolonization of the meiofauna had occurred and abundance and diversity had increased well after 1 year. Wormald (1976) reported the almost complete destruction of meiofauna by a diesel oil spill on a sandy beach in Hong Kong. By the fifth month the aromatics had largely disappeared and the population began to recover; after 11 months, the fauna appeared to be normal. The same general patterns of recolonization after some months was observed in a spill of fuel oil into a stream (Schultz and Tebo 1975). Leppakoski and Lindstrom (1978) observed slow (1-4 year) recovery in an area off an oil refinery after pollution abatement went into effect. The meiofaunal community on the Atlantic coast of Panama was reduced in deeper layers of a sand beach long after the top layer appeared clean because of the depth to which the oil had penetrated (Rutzler and Sterrer 1970). Recolonization of a high energy beach in South Africa was observed within 6 months, though chronic pollution off South African beaches apparently precludes full recovery of shores there (Hennig and Fricke 1980).

Though some organisms bioaccumulate oil, there is little evidence that biomagnification through trophic levels occurs. Shaw and Wiggs (1980) studied hydrocarbons and the intertidal environment at Kachemak Bay, Alaska. They found that animals high in the food web, such as gastropods and urchins, showed no evidence of petroleum contamination. Also, there was no evidence of biomagnification in studies of the Falmouth spill (Burns and Teal 1979). Varanasi and Gmur (1981) studied the physiological mechanisms of benzo-[a]-pyrene and naphthalene uptake in the English sole (*Parophrys vetulus*) when forcefed contaminated sediment and determined that naphthalene is excreted almost immediately by the gills, whereas benzo-[a]-pyrene is metabolized by the liver and transported to the bile. In other research, Varanasi et al. (1981) studied the binding of benzo-[a]-pyrene in English sole livers. Although the sole is a carnivore, and thus would not be expected to ingest the pollutant directly, its flat-in-the-substrate existence could allow it to ingest contaminated sediment by accident while feeding. However, the existence of benzo-[a]-pyrene in the fish is not clear-cut evidence of biomagnification.

Among the outstanding research on oil pollution effects have been the Falmouth spill studies. Because the spill happened quite near the marine science center at Woods Hole, Massachusetts, a number of scientists have studied its long-term effects. To recapitulate the findings over a 10-year period here would not be practical. However, suffice it to say that the return to "normal" in terms of the fauna has taken years (Sanders et al. 1980).

The National Academy of Science has sponsored an update of their treatise on "Petroleum in the Marine Environment." It is currently in preparation and should provide a valuable reference.

3.3 SUMMARY

1. In general the flora and fauna will recover in an area which has been subjected to an oil spill if the area is not re-oiled. Recovery of populations of benthic organisms will take months to years, depending upon wave action, substrate particle size, and the types of organisms present.

2. It is apparent that initial exposure to oil is usually the most devastating period, since the more toxic lighter fractions have not yet volatilized. More research is needed, however, in low energy areas where lighter petroleum fractions continue to be given off slowly, and hence prevent optimum recolonization. Also, the extremely cold environments of the arctic (and antarctic) and subarctic regions present unique ecological problems as degradation of petroleum proceeds more slowly than elsewhere.

3. Though bioaccumulation does occur, evidence for biomagnification is lacking.

CHAPTER 4
SYNTHETIC ORGANIC COMPOUNDS

4.1 AVAILABILITY

Biocides, such as chlorinated hydrocarbons (e.g., DDT and its derivatives; dieldrin, chlordane) and other toxic organics such as polychlorinated biphenyl (PCB) are very tightly adsorbed to sediment particles in the environment. Natural sediments from Calumet Harbor in Chicago, the mouth of the Fox River in Green Bay, Wisconsin, Hope Bay near Fall River, Massachusetts, Tabbs Bay in Houston, Texas, and the Tennessee Chute in Memphis, Tennessee, were studied in the laboratory by Fulk et al. (1975). All of these sediments were contaminated to varying degrees with pesticides and PCB's. The authors found PCB's in 59 out of 64 sediment samples, while DDT and dieldrin were the next most common. After months of testing, with very little or undetectable amounts of these pollutants having been released to the water column in experimental tanks, Fulk et al. (1975) concluded that adsorption of PCB's and pesticides to particulates (i.e., the sediment, here) is much easier than desorption; hence, the commonly observed phenomenon of long-term high levels of pesticides and PCB's in sediment. In a series of laboratory experiments, Chen et al. (1976) found that after 3 months under either aerobic or anaerobic conditions, the amount of soluble chlorinated hydrocarbons released from the sediment in the water column was not detectable. (It should be noted that PCB's are relatively insoluble in water.) This was also generally the case with sediment from Pensacola Bay, Mobile Bay, Oakland Harbor, and the Duwamish Waterway in other laboratory studies (Brannon et al. 1978). In field experiments in the Duwamish Waterway disposal site--heavily contaminated with PCB's--Pavlou et al. (1978) found that the levels of PCB's onsite did not decrease during the 9-month study period, nor did major resuspension of the sediment occur. Conversely, ambient water column PCB values remained the same.

Schnoor (1981) developed a model of dieldrin cycling based on studies of dieldrin in an Iowa reservoir. In any one year, approximately 50% of the dieldrin is exported through the outflow of the reservoir, 40% undergoes sedimentation, and 10% enters the biota (fish in this case). Hoeppel et al. (1978) studied pesticides and PCB concentrations in the sediments of nine confined land disposal areas and found that not only are there close sediment-pesticide associations (PCB's are always associated with suspended solids), but the associations may also depend upon the particle size. For example, DDE is usually associated with clay-sized particles, whereas DDT and DDD are associated with larger particles.

According to Fulk et al. (1975), the factors affecting the release of pesticides/PCB's from the sediment are: (1) the amount of solids compared to the amount of water, (2) the concentration of the pollutant, (3) particle size and organic content, and (4) the amount of oil and grease. The latter are

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important because they are also non-polar, and, hence, tend to concentrate the non-polar pesticides. In a summary of the studies done under contract to the U.S. Corps of Engineers (DMRP contracts), Burks and Engler (1978) concluded that the disposal of pesticide-contaminated sediment probably would not cause significant effects to organisms in the water column. Generally, benthic organisms and predators which feed on benthic organisms would probably run the greatest risk from such contaminated sediments.

4.2 BIOACCUMULATION

In experimental laboratory tests, pesticides of all types have been found to be bioaccumulative in a number of different animals and plants. For example, Fowler et al. (1978) utilized the common benthic polychaete, *Nereis diversicolor*, in a series of aquaria with differing amounts of PCB in the sediments. Uptake of the PCB occurred and the amount of uptake was directly correlated to the amount of PCB in the sediment. Conversely, depuration rates were fastest in those worms which had the highest levels of PCB in the tissues. Nathans and Bechtel (1977) set up a series of laboratory experiments using combinations of natural and artificial substrates contaminated with various labeled DDT derivatives. The marine and freshwater worms *Nepthys californiensis*, *Capitella capitata*, and *Tubifex tubifex* were found to accumulate DDT. *C. capitata* was able to bioaccumulate 50-70 times the concentration in the sediment, while for *N. californiensis*, the factor was 8 and for *Tubifex* the factor was 2. An artificial suspension of particles of alumina were utilized by Courtney and Denton (1976) and treated with the PCB Aroclor 1254 to give total concentrations of 1.25 ppb and 12.50 ppb. In experimental aquaria which contained suspensions of these treated particles plus seawater, quahog clams, *Mercenaria mercenaria*, were kept up to 21 days. After that period, visceral mass PCB concentrations were 1,225 times the 1.25 ppb ambient dosage and 726 times the 12.5 ppb dosage, clearly indicating uptake. These visceral mass levels were almost as high after 6 months of depuration in clean seawater (calculated loss of PCB load = 0.1% of total body load/mo.). In laboratory experiments the clams *Cerastoderma edule* and *Macoma balthica* concentrated PCB's in their tissues at 70-240X the ambient concentration (Langston 1978). Fiddler crabs (*Uca pugnax*) fed detritus contaminated with 10 ppm DDT residues were found to exhibit modified behavior and coordination (Odum et al. 1969).

At a higher trophic level, the hogchoker, *Trinectes maculatus*, a carnivorous flatfish, was utilized in laboratory experiments to determine potential bioaccumulation of mirex from sediment (Kobylinski and Livingston 1975). The fish absorbed considerably more mirex than was lost to the water in the flow-through aquaria. Therefore, Kobylinski and Livingston concluded that, although it is unlikely that this carnivore is ingesting the sediment, it does indeed absorb mirex from the sediment. Kepone, a compound related to mirex, was the subject of laboratory experiments by Rubenstein et al. (1980). Aquaria were set up to determine the effects of kepone in the sediment on the mysid shrimp, *Mysidopsis bahia*, the lugworm, *Arenicola cristata*, and the oyster, *Crassostrea virginica*. Clean sand (as substrate) was treated with kepone to achieve varying concentrations and the animals were exposed to the treated sand. The mysids were very susceptible to the toxic effects of kepone, experiencing 37% mortality at 10 ppm, 30% at 1 ppm, and 20% mortality at 0.1 ppm after 10 days. Oyster shell growth was inhibited at 1 and 10 ppm, and the lugworm ceased burrowing at 10 ppm. Tissue accumulations were surprisingly low: 1.2 ppm/whole body tissue at 10 ppm kepone for oysters; 1.1 ppm at 10 ppm kepone for lugworms.

Peddicord (1980), in laboratory studies using actual slurry suspensions of contaminated sediments, found that uptake of PCB, aldrin, dieldrin, chlordane, and heptachlor were either nonexistent or below detection limits in the mussel, *Californianus mytilus*, but the mussels exhibited a slight (1.5X) elevation in tissue concentrations of DDT and its derivatives over the control group. Likewise, two crustaceans, *Crangon nigromaculata* and *Cancer magister*, showed absolutely no PCB or chlorinated hydrocarbon uptake.

Field studies have generally shown that pesticides are bioaccumulated. Nimmo et al. (1971) found a positive correlation between the amount of Aroclor 1254 (a PCB) in the sediment of Escambia Bay, Florida, and amounts in body tissues of the fiddler crab. In the James River, Virginia, where large amounts of kepone were released from a chemical plant at Hopewell, Virginia, between 1966-75, kepone levels were characterized in organisms (Huggett et al. 1980). The area from Hopewell downriver to the estuarine areas of Norfolk and Newport-News, about 161 km (100 mi), is contaminated with kepone. Though no toxic or chronic effects were observed among the organisms surveyed, they noted that levels of kepone in tissues were high. For example, largemouth bass contained an average of 2.4 μg kepone/g tissue (wet wt.) and female blue crabs had 0.81 μg kepone/g tissue. These levels exceed the maximum acceptable FDA levels for kepone in fish (0.30 μg/g) and crabs (0.4 μg/g) in food for human consumption. Hansen et al. (1976) reported that kepone is very bioaccumulative and persistent in estuarine organisms. They cited oysters, grass shrimp, and fish as having 425-20,000 times the concentration of the surrounding water in their tissues. However, oysters were reported to depurate 90% of the accumulated kepone within 4 days; fish 40-50% within 3 weeks (Hansen et al. 1976).

PCB's entering a creek from a paper mill effluent stream in Oklahoma have been detected in the water column (Hunter et al. 1980b). Further, concentrations of PCB's were significantly greater in detritivores than in either omnivores or predators. Carp in this stream averaged 40 times the PCB levels found in carp in the rest of the state. Many of the carp in this stream exceeded the maximum allowable level of 5 μg/g. Bremer (1979) found levels of PCB in fish in the Sheboygan River which ranged from 8.3-750 ppm and suspected strongly that sediment, contaminated by a diecasting company, was responsible. Results of a field experiment by Stout and Lewis (1977), however, were ambiguous with regard to the effect of PCB-contaminated sediment on selected caged animals in an open water disposal site. That is, ranges of PCB values were very broad in English sole (*Parophrys vetulus*); there were no differences in control vs. experimental Alaskan pink shrimp (*Pandalus borealis*); and, finally, the mussels used (*Mytilus edulis*) were apparently already naturally high in PCB's. Mud snails in a Japanese lake ingested PCB from sediment, but with apparently no serious consequences (*Nakanishi* 1981). Further, Ai et al. (1980) found that PCB-contaminated sediment in Tagonoura Bay, Japan, was not reflected in excessive values in fish and plankton. Schnoor (1981) noted that the level of dieldrin in fish tissue in the Coralville Reservoir, Iowa, was less than the 300 ppb "safe level" recommended by the FDA. Spoil sites containing mixtures of chlorinated hydrocarbons were found to be toxic to larval and juvenile crabs (Pearce 1972). And Krebs and Valiela (1978) found significantly fewer fiddler crabs (*Uca pugnax*) in experimental field plots with sludge containing aldrin and dieldrin.

The pesticide toxaphene, commonly used on agricultural crops, was the subject of studies by Gallagher and Wolf (1980), in which they injected the chemical into experimental plots of *Spartina alterniflora*. Pollutant levels were measured in plant tissues at intervals afterward. The toxaphene not only was bioaccumulated by the plants, but was also available to the food web as the tissues (leaves and stems) decayed and fragmented. That is, the detrital material could be accumulated and biomagnified throughout the food web. Biomagnification apparently does occur with the chlorinated hydrocarbons and other pesticides and organics, but the extent to which such transfer of the various compounds occurs is not well-known. Organochlorine residues (PCB, chlordane, DDT) were found in Lake Texoma, Oklahoma, and in various trophic levels of 11 species of fish within the lake (Hunter et al. 1980a). It was found that chlordane was much more prevalent among herbivores and detritivores than among carnivores. PCB's and chlordane, on the other hand, were found in most species and at all trophic levels, while o,p'-DDT and p,p'-TDE were found mostly in detritivores, rarely in herbivores and not at all in carnivores. Paasivirta et al. (1980) discussed the presence of chlorinated phenols in food chains and indicated that these compounds accumulate like PCB's and DDT. Kepone exists at all trophic levels in the James River, and it was postulated that assimilation pathways are either direct to an organism or via passage through the food chain from one group to another (Huggett et al. 1980). Bivalves (*Rangia cuneata*) accumulated 10-23% of the sediment concentration of dielurin in San Antonio Bay sediment, but blue crabs (*Callinectes sapidus*) which were fed these clams exhibited concentration factors up to 6.8 times the levels in the clams (Petrocelli and Anderson 1976).

In a general ecological sense, it seems clear that sediments, acting as sinks for pesticides and other organic pollutants, will continue to be important as potential sources of the materials to the biota. Several recent reviews of pollutants mention these chemicals in that regard (Grant 1976; Reish et al. 1978; Peddicord 1980; and DePinto 1981). However, Swartz and Lee (1980) perhaps sum it up best by expressing a general feeling in pollution ecology that there are more gaps than facts in our knowledge at this time. That is, adequate knowledge about trophic transfer of *all* classes of pollutants, not just pesticides, is lacking.

4.3 SUMMARY

1. Though much literature is available on the toxicity of chlorinated hydrocarbons in solution, via *in vitro* toxicity tests, more information is needed on *in vivo* sediment-organism effects.

2. The available information indicates that most of the compounds have strong bioaccumulation and biomagnification properties, probably because they are quite soluble in fatty tissues. However, the effects in the long term (i.e., chronic pollution) of small quantities of strongly adsorbed compounds in the sediment are not adequately known.

CHAPTER 5
RADIONUCLIDES

5.1 AVAILABILITY

There are few data on the long-term biochemical behavior of transuranium elements in the environment after they have weathered and reached equilibrium. The weathering rates are not yet known; also, it is experimentally difficult to measure the long-term behavior of these elements because of their long (e.g., hundreds of years) half-lives (Weimer et al. 1980). However, they may be acted upon in the environment as are their stable counterparts (Foerstner 1980). Common sources of radionuclides in the environment include nuclear fuels (e.g., uranium-235 and plutonium-238), fission products from the use of nuclear fuels (cesium-137), activation products resulting from nuclear fuel reactor vessels and weapons (zinc-65 and iron-55) and from mining and milling operations (radium-226) (Foerstner 1980). Hauschild (1980) discussed the transport and accumulation of radionuclides in the Columbia River sediment, which is the receiving stream for wastes from the Hanford group of nuclear reactors. Data were available on at least eight radionuclides (chromium-51, zinc-65, scandium-46, iron-59, manganese-54, antimony-124, cobalt-58, and cobalt-60). In some places the upper 1.5 m of sediment (sand) contained an equal distribution of radionuclides. Concentrations in finer sediments were highest just at or near the surface. Theoretical work on plutonium and americium biokinetics indicates that the effects of pH and Eh on complexion reactions are probably the cause of great variability in their distribution and the sedimentation and sediment adsorption represent major reconcentration processes for actinides released in surface waters (Murray and Avagodro 1979, 1981).

Plutonium (Pu), one of the principal nuclear fuels and one of the most toxic of the radionuclides, is difficult to assess in the laboratory because it may exist simultaneously in several oxidation states (+3, +4, +5, and +6) Weimer et al. 1980). A short review of available information on Pu in the environment was done by Schell and Watters (1975), who determined that Pu exists in the environment in particulate, soluble and colloidal physical-chemical states. Thus, the availability of radioactive materials appears to be dependent upon a number of physical manifestations of the elements. Dayal et al. (1979) reported, for example, that some of the radioactive cesium waste (cesium-137 and cesium-134) buried in canisters at a depth of 2,800 m in the Atlantic, had leaked from the canisters over a 15-year period. Though only 0.3% of that waste had escaped into the sediment, the authors postulated that bioturbation by worms and other organisms which burrow through the sediment may be responsible for transport of the radionuclides from the cannisters to the sediment.

5.2 BIOACCUMULATION

The transfer of radionuclides from whatever source (nuclear power plants, reprocessing plants, weapons use, etc.) is of prime concern, especially with the long half-lives of many elements. Koyanagi et al. (1978) utilized a demersal fish, *Kareius bicoloratus*, as an experimental subject for the determination of the short-term adsorption pathways of sediment-bound radionuclides. The fish presumably ingests sediment along with food while feeding on the bottom. Acting on this assumption the authors used prepared labeled sediment and force-fed the capsules to the fish. The results indicated that much of the radioactive material was excreted within 24-48 hours of ingestion (70% loss of zinc-65; 80% loss of manganese-54 and cobalt-60: 97% loss of iron-59). High radioactivity levels in intestine, liver, and kidney suggested rapid transfer through these organs. Uptake of americium and plutonium by the polychaete, *Nereis diversicolor*, from naturally contaminated substrates was the subject of research by Beasly and Fowler (1976). Uptake of both metals was small. Water may be the predominant pathway for plutonium accumulation. Working with the marine polychaete, *Arenicola marina*, the amphipod, *Corophium volutator*, and the clam, *Scrobicularia plana*, Miramaud et al. (1982) found that transfer factors for americium-241 and plutonium-238 were low (<1) after 2 weeks in the sediment, but also that *Corophium* uptake was 10 times greater than *Scrobicularia* and 50 times greater than *Arenicola* for both elements. It was found in Japan by Ueda (1981) that cobalt-60, released along the coast and spread by tides and currents, is adsorbed by sediment and infauna. He further stated that the concentration factor by gulfweed was high. Also in Japan, Okano et al. (1979) studied the uptake of strontium-90 and cesium-137 by carp and shellfish in a lake.

Schell and Watters (1975) studied the uptake of Pu in the Eniwetok and Bikini atolls and found that the invertebrates and vertebrates had low values. Fish muscle, for example, ranged from 0.001-0.2 p Ci/g wet muscle tissue. Pu uptake by the crab, *Cancer pagurus*, occurred mainly as surface adsorption to gills and exoskeleton (Guary et al. 1976). Further, the flatfish, *Pleuronectes platessa*, accumulated Pu from sediment mainly in the gut during feeding and muscle tissue was fairly low in Pu concentration. Guary et al. (1976) concluded that the edible parts of these animals do not constitute a hazard to man.

In a laboratory study of the uptake of Pu by crabs, Fowler and Guary (1977) determined that within 2 weeks, the animals depurated 90% of the radioactivity contained in "hot worms" which were fed to them. Of the remaining Pu, the hepatopancreas retained the greatest amounts (43-85%), followed by the shell (8-43%) and finally by the gill and muscle tissue (5-10%). In the Oregon coastal area, undetectable levels of zinc-65 in sediment were bioconcentrated by a brittle star to detectable levels (Carey 1969). A laboratory study by Cross et al. (1967) indicated that an amphipod, *Anonyx* sp., retained 55% of the zinc-65 ingested with contaminated brine shrimp (*Artemia* sp.).

There apparently has been little work on the biomagnification of radionuclides. Schell and Watters (1975) reported that Pu concentration in body tissues decreases with increases in trophic level. They list concentration factors of several thousand for algae, 760-1,600 for benthos, and 1.5-7 for piscivorous fish. Resuspension of sediment was thought to be a source to the environment in this case.

5.3 SUMMARY

1. More long-term field data are needed. The problem is compounded by long half-lives of the transuranium elements and unknown weathering rates.

2. In general, more information is needed on bioaccumulation and especially on biomagnification, which appears to be negligible.

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KEY WORDS: COPPER, PLANTS, MINING, JAPAN

Ai K., Y. Igarashi, and Y. Harada. 1980.

EXAMINATION AND ANALYSIS OF THE ACCUMULATION OF HEAVY METALS. I. THE EXAMINATION OF ENVIRONMENTAL POLLUTION IN FISHERIES. PCB. (Abstract only. Transl. from Japanese.)
Pages 126-127 in Shizuoka Prefecture Water Experiment Station Work Report Vol. 1979.

PCB had been deposited in the mud of the sea bed in the port of Tagonoura, Huji City. This study examines effects of PCB on plankton and fish in the sea surrounding the port. The PCB analysis was carried out using plankton and five primary species of fish, including the horse mackerel. The results indicate that all values are not above the regulated value of 3.0 ppm.
KEY WORDS: PCB, PLANKTON, FISH, JAPAN

Anderson, J.W., L.J. Moore, J.W. Blaylock, D.L. Woodruff, and S.L. Kiesser. 1977.

BIOAVAILABILITY OF SEDIMENT-SORBED NAPHTHALENES TO THE SIPUNCULID WORM, PHASCOLOSOMA AGASSIZII.
Pages 276-285 in D.A. Wolfe, ed. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

The peanut worm, Phascolosoma agassizii, was exposed to petroleum hydrocarbons from Prudhoe Bay crude oil. Uptake and release of naphthalene and alkylnaphthalenes were compared for worms exposed to hydrocarbons in solution, oil on the surface of sediments and oil mixed in sediment. Hydrocarbon levels in the sediments were high (475-765 ppm) yet survival was above 90%. After 2 weeks in the sediment, either oiled on the surface or mixed thoroughly with oil, animals contained 2-4 ppm of total naphthalenes. This may represent contaminated sediment in the gut. Depuration of naphthalenes was rapid, perhaps an indication of egestion. After 2 weeks of depuration, worms released naphthalenes to approach background levels. It does not appear that significant bioaccumulation of naphthalenes occurs from hydrocarbon fractions bound to sediment.

KEY WORDS: POLYCHAETE, NAPHTHALENE, OILS

Anderson, J.W., R.G. Riley, and R.M. Bean. 1978.

RECRUITMENT OF BENTHIC ANIMALS AS A FUNCTION OF PETROLEUM HYDROCARBON CONCENTRATIONS IN THE SEDIMENT.
J. Fish. Res. Board Can. 35:776-790.

Three separate field installations, consisting of clean and oiled sediment in fiberglass or PVC trays, were placed in the intertidal zone of Sequim Bay, Washington, to determine rates of hydrocarbon depuration and recruitment of benthic organisms. Detailed chemical analysis, with hexane extraction, silica gel chromatography and capillary column chromatography, were conducted to assess sediment concentrations of various hydrocarbon fractions with time. In a period of 100 days, total hydrocarbons in surface-oiled trays (installations I & II) had decreased by 82-88%, while the thoroughly mixed tray (installation III) still contained 73% of the oil after 9 months. Initial concentrations of oil in sediments upon field emplacement were 5,000-6,000 ppm in cases I & II, while case III had 700 ppm. At these concentrations, no substantial inhibition of recruitment by benthic organisms was observed. However, with the fast rates of depuration in sediments I & II, the amounts of oil in the sediment were low when the first biological samples were retrieved at 130 days. Therefore, the biological results were rather ambiguous. Also, the authors admit that differences in the set-out times of the three cases, plus differing lengths of time in the field, plus seasonal spawning cycles of various organisms might have affected the results. In general, the dominant species, three polychaetes (*Ophiodromus pugettensis*, *Armandia bioculata*, and *Platynereis bicanaliculata*) and two mollusks (*Mysella tumida* and *Psephidia lordi*) were similarly abundant in both the control and the experimental stations. The authors suggest that perhaps also the period of months in these experiments is not really long enough to promote differences in faunal populations between oiled and unoiled sediments. They point out that very few previous studies have attempted to integrate known quantities of oil in sediment with biological consequences in a field experiment.

KEY WORDS: PETROLEUM, BENTHOS, WASHINGTON, OILS

Atlas, R.M., A. Horowitz, and M. Busdosh. 1978.

PRUDHOE CRUDE OIL IN ARCTIC MARINE ICE, WATER AND SEDIMENT ECOSYSTEMS: DEGRADATION AND INTERACTIONS WITH MICROBIAL AND BENTHIC COMMUNITIES.
J. Fish. Res. Board Can. 35:585-590.

Oil effects were observed by experimentally contaminating sediment near Point Barrow, Alaska. Oil contamination of sediment resulted in mortality of indigenous invertebrates. In these mortality studies, the sediment was scooped from the bottom and put in trays then exposed to oil. By doing this, however, disturbance as well as oil is a factor in species behavior. Recolonization of sediments began shortly after oil contamination but benthic communities were significantly different in oil-contaminated sediment compared with the control. Prudhoe Bay crude oil is toxic to some amphipods, so amphipods were significantly fewer in number in oil-contaminated sediments. Isopods were highly oil-resistant and were found in equal numbers in both oiled and control sediments. Some polychaetes were attracted to oil while some species were affected by oil toxicity.

This paper pointed out that ice greatly restricted losses of light hydrocarbons. Biodegradation of oil did not significantly alter the relative percentages of hydrocarbons in the residual oil. Because of these factors, petroleum hydrocarbons will remain in arctic ecosystems for prolonged periods after contamination.

KEY WORDS: OILS, ARCTIC, INVERTEBRATES

Bak, R.P.M., and J.H.B.W. Elgershuizen. 1976.

PATTERNS OF OIL-SEDIMENT REJECTION IN CORALS.
Mar. Biol. 37:105-113.

Concerned about oil spills on the high seas and the potential for impacts on corals, the authors tested the effects of oil-polluted sediment on living coral tissue in the laboratory in Curacao. The sediment was clean sand. The oils were three types of crudes and two types of refineds. Clean sand was used as a control. In all, 19 species of hermatypic corals were tested using varying amounts of oiled sediment (0.75 g, 1.5 g, and 3.0 g) which were dropped onto a 3 cm circle of coral surface tissue. Each experiment was performed twice on two different colonies of the same species of coral. Rejection efficiency was determined as the amount of time necessary to clean the colony surface of sediment.

The results indicated that the rejection efficiency in a given species was the same for oiled sand as for clean sand. Further, there was no evidence of adsorption of oil to living tissues nor was there active ingestion of oil by the corals. Rather, ciliary and tentacular movements removed the sediment, whether oiled or not. The presence of mucus appeared to be involved in effective removal. The authors concluded that it is the water-soluble toxic fraction of oil in seawater which is probably more harmful to corals than *in situ* physical contact. No toxicity studies were performed, however.

KEY WORDS: OILS, CORAL, CURACAO, POLYCHAETE

Baker, J.M., I. Campodocino, L. Guzman, J.J. Texera, B. Texera, C. Venegas, and A. Sanhueza. 1976.

AN OIL SPILL IN THE STRAITS OF MAGELLAN.
Pages 441-471 *in* J.M. Baker, ed. Marine Ecology and Oil Pollution. John Wiley & Sons, New York.

Approximately 50,000 tons of Arabian light crude and Bunker C oil were lost off the Straits of Magellan, Chile. About 70% of the oil washed ashore,

20% evaporated, while 10% either dissolved or was incorporated into the sediments. The area has a high energy wave regime so the shores were relatively poor in macroflora and macrofauna. Kelp beds and associated communities appeared unaffected. Some mussels beds and algae were affected, but due to the high tidal exchange, very few dead mussels were observed. It was estimated that a total of 3-4,000 cormorants and penguins were killed, though apparently this was not a significant portion of the bird populations. There was only one report of oil-related damage to fisheries, probably because most of the oil was north of the major fishing grounds.
KEY WORDS: OILS, CHILE

Banus, M.D., I. Valiela, and J.M. Teal. 1979.

LEAD, ZINC, AND CADMIUM BUDGETS IN EXPERIMENTALLY ENRICHED SALT MARSH ECOSYSTEMS.
Estuarine Coastal Mar. Sci. 3:421-430.

A salt marsh was experimentally treated with a metals-containing sludge fertilizer. Lead was largely retained by the surface sediments, with 6-8% being taken up by marsh grasses. Lead in grass tops was exported to deeper waters as detritus. About 2% of the zinc added was exported in grass detritus, while 16-45% was lost by undetermined mechanisms. At a dosage rate of 15 mg/m^2/yr, about 80% of the cadmium added was retained in the sediments, while at a dosage of 43 mg/m^2/yr, 65% of the added cadmium left the plot in dissolved form. Eutrophication, more specifically nitrogen addition to the water, resulted in increased movement of these metals into coastal water due to increased production of grasses. These increases were around an order of magnitude for lead and somewhat less for cadmium and zinc.
KEY WORDS: METALS, ESTUARIES, BIOACCUMULATION, MASSACHUSETTS, CADMIUM, LEAD, ZINC

Barton, D.R., and R.R. Wallace. 1979.

THE EFFECTS OF AN EXPERIMENTAL SPILLAGE OF OIL SANDS TAILINGS SLUDGE ON BENTHIC INVERTEBRATES.
Environ. Pollut. 18:305-312.

A minor spillage of oil sands tailings sludge (sludge volume was 16% of the area's water flow) was introduced to a part of a river in northern Alberta. These tailings come from mining of oil sand deposits in northern Alberta to produce synthetic crude oil. A 60% reduction in the standing stock of benthic invertebrates occurred throughout a four-week period in the immediate area of the spill. However, numbers of oligochaetes, elmids, and chironomids did not decrease significantly in the oiled area. Sensitive organisms decreased in abundance over an area of at least 30 m downstream, but total density of fauna was not affected at the middle to lower sites. The sludge contained fine silt, heavy sticky oils and heavy metals. Fine silt mixed with the sticky oils probably constituted the principal hazard to aquatic communities. Recovery following this type of spill would be slow, since the fine sediment adhering

to the stream bed would be relatively resistant to resuspension. No recovery was observed within the one-month duration of the study.
KEY WORDS: OILS, BENTHOS, CANADA

Beasley, T.M., and W.S. Fowler. 1976.

PLUTONIUM AND AMERICIUM: UPTAKE FROM CONTAMINATED SEDIMENTS BY THE POLYCHAETE *NEREIS DIVERSICOLOR*.
Mar. Biol. 38:95-100.

Nereis diversicolor was exposed to marine sediments contaminated with plutonium and americium, either through nuclear fallout or by the release of liquid waste effluent from a nuclear fuel reprocessing plant. Uptake of both metals was small. It is postulated that water may be the predominant pathway for plutonium accumulation. Uptake of americium from sediments contaminated by waste effluent was greater than that from nuclear test debris sediment.
KEY WORDS: POLYCHAETES, HEAVY METALS, RADIONUCLIDES

Bender, M.E., J.L. Hyland, and T.E. Duncan. 1974.

EFFECTS OF AN OIL SPILL ON BENTHIC ANIMALS IN THE LOWER NEW YORK RIVER, VIRGINIA.
Pages 257-259 *in* Proc. Mar. Pollut. Monit. Symp. Wkshp., Natl. Bur. Standards, Washington, D.C.

A combination of field and laboratory studies were used to determine the effects of oil on estuaries. Three months after the spill, only half the number of species were in affected areas than in non-affected areas. After 1 year, most faunal species had recovered, though individual numbers were still low. Laboratory tests were only done for toxicity of water soluble components of oil. It was found that there is a general resistance of mollusks to acute oil toxicity. Species richness and faunal similarity appeared to give a better indication of the effects of the oil than did the diversity calculation.
KEY WORDS: OILS, BENTHOS, ESTUARIES, VIRGINIA

Bender, M.E., E.A. Shearls, L. Murray, and R.J. Huggett. 1980.

ECOLOGICAL EFFECTS OF EXPERIMENTAL OIL SPILLS IN EASTERN COASTAL ESTUARIES.
Environ. Int. 3:121-133.

One and one-half barrels of oil were pumped onto each 810 m^2 test area forming, on the average, a 0.7 mm thick layer of oil on the site. Most weathered oil disappeared after 1 week, while fresh crude stayed from 3-5 weeks. Marsh grasses exposed to oil produced less than ½ the biomass as grasses in control plots. A large difference in biomass was still present in the second year growth as well. Benthic biomass was less in oiled than in control areas. The greatest adverse effects were on polychaetes, amphipods and oligochaetes. Nereid polychaetes were quickly affected by oil, even though some literature

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says that they are very tolerant. Over 1 year was required for the polychaetes to recover. Polychaetes responded more to fresh than to weathered oil. Obligochaete numbers in oil stayed constant and relatively low for 2 years, then returned to normal levels by the third year.

Burrowing activity may be hampered by oil, thus altering feeding patterns and increasing susceptibility to predation. Microbial degradation is probably the major factor in removing petroleum hydrocarbons once they are in the sediment.

KEY WORDS: OILS, SALT MARSH, VIRGINIA

Blom, B.E., T.F. Jenkins, D.C. Leggett, and R.P. Murrmann. 1976.

EFFECT OF SEDIMENT ORGANIC MATTER ON MIGRATION OF VARIOUS CHEMICAL CONSTITUENTS DURING DISPOSAL OF DREDGED MATERIAL.
Contract Rep. D-76-7. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 148 pp. + Append.

Part of this paper is a literature review of the interactions of organic matter in the physical-chemical reactions between metals and organics in sediments. The literature review indicated that, indeed, the chemistry of dredged material is quite complex and poorly understood.

The second part consists of a report on laboratory studies using sediments from the Hudson River, Shooters Island Reach and Newton Creek in the New York area, and from the Saginaw River (Bay City), the Rouge River (Detroit), and the Maumee River (Toledo) in the Great Lakes area. The organic carbon component of the sediments was determined in the laboratory, as were the metals and nutrients. The sediments had been stored cold and under nitrogen prior to analyses. In long-term experiments, sediment samples were placed in cylinders with seawater or freshwater and kept at 10°C and at a dissolved oxygen concentration of 4-6 ppm for 4 months. Organic carbon and metals in the water column were measured at intervals. Some constituents did migrate from sediment to water column in the cylinders (e.g., orthophosphate, Cd, Mg). The long-term results under both freshwater and saltwater conditions were that there is no evidence that total organic carbon directly controls the release of either metals or nutrients during spoil disposal. The authors did point out, however, that sediments containing significant amounts of petroleum hydrocarbons exhibited a typical behavior with regard to complexing capacity and iron and orthophosphate concentrations in the overlying water.

KEY WORDS: MOBILITY, ORGANIC CARBON, REVIEW

Boucher, G. 1980.

IMPACT OF THE *AMOCO CADIZ* OIL SPILL ON INTERTIDAL AND SUBLITTORAL MEIOFAUNA.
Mar. Pollut. Bull. 11:95-101.

Sensitivity of meiofaunal groups to petroleum is variable, depending on the spill conditions. Oligachaetes, polychaetes and turbellarians are generally resistant to oil pollution, while ostracods are rather sensitive. Harpacticoid densities can be very sensitive to spilled oil, though both positive and negative effects have been reported. Nematodes, the dominant meiofaunal group, are also affected to varying degrees. Intertidally, nematode numbers generally decreased for the first few months, while sublittorally no significant changes in nematode densities were noted for up to 1 year after the spill. There is an indication that there is a long-term effect of hydrocarbons on nematodes with a fast regeneration time.

KEY WORDS: OILS, MEIOFAUNA, FRANCE

Bradford, W.L., and S.N. Luoma. 1980.

SOME PERSPECTIVES ON HEAVY METAL CONCENTRATIONS IN SHELLFISH AND SEDIMENT IN SAN FRANCISCO BAY, CALIFORNIA.
Pages 501-532 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

The authors discuss historical and present-day conditions in San Francisco Bay in terms of sediment, metal content and shellfish populations in the bay. In the early part of this century, commercial harvesting of oysters (*Crassostrea gigas*) and other shellfish occurred in the bay. However, by 1905, the shellfish populations were no longer of commercial quantity. It has been thought that perhaps the accumulative effects of mining in rivers upstream (the Sacramento and San Joaquin Rivers) caused this demise. In present times, there are parts of the bay (e.g., Redwood Creek; Palo Alto) in which high levels of metals are found in tissues of the oysters, *Crassostrea gigas* and *C. virginica*, the soft-shelled clam, *Mya arenaria*, and the mussel, *Mytilus edulis*. The metals in question are Cd, Cr, Cu, Hg, Pb, and Zn. Also, spat of *C. gigas* and *C. virginica* will not grow adequately on the bottom of the bay. The spat will grow on stakes or in trays in the water column, however.

The biological effects are hard to assess, because in some areas of the bay shellfish species are quite abundant (e.g., *Mya arenaria*, *Tapes japonica*). The authors concluded that it seems unlikely that metals caused the 1905 demise. Rather, it is more likely that changes in circulation patterns plus increased siltation caused by extensive dredging and filling were responsible. There is little evidence at present to indicate that the benthic community is under baywide stress from heavy metals.

KEY WORDS: HEAVY METALS, SHELLFISH, ESTUARIES, CALIFORNIA

Brannon, J.M., J.R. Plumb, and I. Smith. 1978.

LONG-TERM RELEASE OF CONTAMINANTS FROM DREDGED MATERIAL.
Tech. Rep. D-78-49. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 66 pp. + Append.

Substrates from various known contaminated areas (including Pensacola Bay, Mobile Bay, Oakland Harbor, Ca., and the Duwamish Waterway, Wa.) were sampled. The samples were sealed, iced and transported to the Vicksburg Laboratories of the U.S. Army Corps of Engineers for studies on the short-term and long-term leaching of pollutants under quiescent and agitated conditions. Air was slowly bubbled under each condition to keep the milieu aerobic.

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Under quiescent conditions, there was sometimes net movement to the sediment from the water column (e.g., Mn). In other cases, there was some net release of contaminant from the sediment to the water over time (e.g., As, Hg, and Pb). For example, the amount of Hg which was released from the sediment to the water differed little at 4 months and at 8 months. PCB's were generally not released, or the amounts released were below the detection limit of 2 μg/l. The quiescent samples remained at a pH of around 8.

The authors concluded that very short-term tests (i.e., the elutriate method) do not accurately predict long-term water quality impacts of dredged material disposal.

KEY WORDS: ELUTRIATE, LEACHING

Bremer, K.E. 1979.

PCB CONTAMINATION OF THE SHEBOYGAN RIVER, INDIANA HARBOR AND SAGINAW RIVER AND BAY.
Pages 261-287 *in* S.A. Peterson and K.K. Randolph, eds. Management of Bottom Sediments Containing Toxic Substances. Proc. 4th U.S.-Japan Experts Meet., Tokyo. USEPA, Corvallis, Oreg. EPA 600-3-79-102.

In the Sheboygan River, a diecasting factory was the major source of PCB's. At the plant site, patches of contaminated substrate, which leaches into the water, had a concentration of up to 120,000 μgPCB/g wet sediment. Levels in the river sediments went from 0.9 to 970 μg/g. In fishes, where the maximum allowable PCB concentration is 5 ppm, levels were found ranging from 8.3 to 750 ppm. PCB's were the only chemicals which were present at dangerous levels in this river. In Indiana Harbor, the PCB's occurred in highest concentrations upstream and decreased toward the mouth of the river. Hydrocarbons and metals were also found in high concentrations here. In fact, high pollutant levels occurring in Lake Michigan made finding potable water very difficult in the area. The authors suggest several recommendations for dredging restrictions in these contaminated areas: levels of metals and hydrocarbons should not be above the ambient level more than a few hundred yards from the dredge site; sediments should be chemically fixed; containment areas (i.e., land placement areas) should be lined with an impermeable liner or barrier if high levels of pollutants are detected in sediment to be spoiled.

KEY WORDS: PCB, MICHIGAN, WISCONSIN

Bryan, G.W., and L.G. Hummerstone. 1971.

ADAPTATION OF THE POLYCHAETE *NEREIS DIVERSICOLOR* TO ESTUARINE SEDIMENTS CONTAINING HIGH CONCENTRATIONS OF HEAVY METALS I. GENERAL OBSERVATIONS AND ADAPTATIONS TO COPPER.
J. Mar. Biol. Assoc. U.K. 51:845-863.

The concentration of copper in *Nereis diversicolor* is roughly related to the total concentration in the sediment and particularly high concentrations are found where mining pollution occurs. In contrast, the concentration of zinc in *Nereis* remains relatively constant despite wide variations in the environment and, therefore, appears to be accurately regulated.

In worms from different estuaries, concentrations of copper have been related to those of the sediments and interstitial water. Copper uptake over the body appears to be important. In animals from polluted areas, much of the metal is deposited in the epidermis of the body wall and in the parts of the nephridia.

Tolerance to a metal is specific; the animal is not necessarily tolerant of other metals. High-copper animals survive in polluted areas because they have developed a tolerance to the toxic effects of copper which is neither readily lost, nor readily gained by non-tolerant animals. This is similar to plants on old mine dumps where populations of metal-tolerant land plants have become established.

KEY WORDS: METALS, POLYCHAETE, ESTUARIES, ENGLAND, COPPER, ZINC

Bryan, G.W., and L.G. Hummerstone. 1973.

ADAPTATION OF THE POLYCHAETE NEREIS DIVERSICOLOR TO ESTUARINE SEDIMENTS CONTAINING HIGH CONCENTRATIONS OF ZINC AND CADMIUM.
J. Mar. Biol. Assoc. U.K. 53:839-857.

Concentrations of zinc and cadmium in the polychaete, Nereis diversicolor, have been compared with those of the sediments in the estuaries of rivers which drain old metaliferous mining areas of southwest England. Whereas, in the sediments concentrations of zinc varied by a factor of 30 (from about 100 to 3,000 µg/g), concentrations of zinc in the worms varied by only 2.7 (from 130-350 µg/g dry weight). Concentrations of cadmium in the sediment varied by a factor of 46 (range .2-9.3 µg/g). The concentrations in the worms were roughly proportional to sediment concentrations by a factor of 45 (from .08 to 3.6 µg/g). These results suggest that zinc is regulated by the worm, whereas cadmium is not.

Differences between the rates of absorbtion of zinc and cadmium may depend on both the chemical form of the ions and differences in ways in which they are absorbed and transported inwards. Intake of zinc is increased by absorption of contaminated food. The worm's rate of absorption of cadmium is influenced by concentration of zinc in solution.

Populations from high-zinc sediments are better at regulating zinc than normal populations and are more resistant to zinc than normal worms; however, metal toxicity increases with lower salinities.

KEY WORDS: METALS, POLYCHAETE, ENGLAND, ESTUARIES, CADMIUM, ZINC

Bryan, G.W., and L.G. Hummerstone. 1978.

HEAVY METALS IN THE BURROWING BIVALVE SCROBICULARIA PLANA FROM CONTAMINATED AND UNCONTAMINATED ESTUARIES.
J. Mar. Biol. Assoc. U.K. 58:401-419.

The use of a common bivalve in English estuaries as an indicator organism in the long-term uptake of heavy metals is the subject of this study. Scrobicularia plana were assayed for metals (Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in two different estuaries: the polluted Gannel and the relatively unpolluted Camel, which are about 20 km apart on the north coast of Cornwall, in southwest England. The Gannel drains an old lead mining area (with associated Ag, Zn and Cu) which was active between 1845 and 1885. The Camel is also associated with mining, but shows little signs of contamination.

Whole soft parts or tissues from 5-10 animals were pooled and digested in nitric acid for analyses of the 10 metals. In large animals taken from the polluted Gannel, over 90% of the Pb, Co, Cd, and Zn was found in the digestive gland, suggesting that the metals were chiefly absorbed from the ingested sediment. Values for these same metals were very much lower in the digestive glands of animals from the Camel estuary. Further, over 50% of the Cr, Mn, and Ni were also found in the digestive gland, and in both populations of clams, the digestive gland contained the highest concentration of most metals. With the exception of Fe and Mn, which were independent of size, all metal uptake increased with increasing size of the animal.

When animals were exchanged between the two estuaries and monitored *in situ* (out of about 100 animals, 4-5 were recovered and analyzed at intervals), it was found that Mn and Fe were absorbed or lost most rapidly, followed by Ag, Cu, Cr, and Ni. Levels of Pb, Co, Cd and Zn approached native animal levels very slowly--after 1 year, the equilibration process was not complete.

KEY WORDS: METALS, MOLLUSKS, ESTUARIES, ENGLAND

Bryan, G.W., and H. Uysal. 1978.

HEAVY METALS IN THE BURROWING BIVALVE *SCROBICULARIA PLANA* FROM THE TAMAR ESTUARY IN RELATION TO ENVIRONMENTAL LEVELS.
J. Mar. Biol. Assoc. U.K. 58:89-108.

A series of studies on a bivalve common to English estuaries is described. The clams, *Scrobicularia plana*, were collected in the Tamar estuary, near Plymouth and analyzed for various heavy metals (Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) over a span of 5 years at up to nine intertidal mudflat stations. This bivalve lives at depths up to 25 cm, so the interstitial water and the sediment at depth were also analyzed. Seasonal variations were detected in some of the tissue concentrations of metals. For example, Fe and Zn were highest in winter-spring and lowest in summer. Mn peaked in summer. Cu, on the contrary, showed little change regardless of season.

The paper details levels of all of the metals and indicates how much of each was absorbed by the clams and what the sites of absorption were. For example, about 75% of the Cd, Co, Cr, Ni, Pb, and Zn were found in the digestive gland. The bioavailability of the metals to the animals was found to decrease with distance from the mouth of the estuary. The authors attribute this to concomitant decreases in interstitial salinity.

KEY WORDS: MOLLUSKS, METALS, ESTUARIES, ENGLAND

Burks, S., and R.M. Engler. 1978.

WATER QUALITY IMPACTS OF AQUATIC DREDGED MATERIAL DISPOSAL (LABORATORY INVESTIGATIONS).
Tech. Rep. DS-78-4. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 45 pp.

This is a summary paper of U.S. Army Corps of Engineers Dredged Material Research Project (DMRP) reports which deal with the availability of metals,

pesticides, oil and grease, and nutrients in spoil material upon the biota. The authors concluded from the numerous papers that the effects of dredged material disposal in open water are temporary and are usually restricted to the immediate area of disposal. Also, the release of metals during disposal in open waters is short-lived. The heavy metals are soon sorbed to suspended particles, such as iron hydrous oxides, and precipitate to the bottom. The potential for pesticides to cause harm to water column animals is minimal. However, the authors point out the potential hazard to benthic organisms which attempt to recolonize sediments contaminated by pesticides.
KEY WORDS: DREDGED MATERIAL, REVIEW

Burns, K.A., and J.M. Teal. 1979.

THE WEST FALMOUTH OIL SPILL: HYDROCARBONS IN THE SALT MARSH ECOSYSTEM.
Estuarine Coast. Mar. Sci. 8:349-360.

This study is a 7-year monitoring of sediments contaminated in a 1969 spill of No. 2 fuel oil. All organisms were contaminated initially. Most of the oil seeped into the anoxic sediments and slowly spread to unoiled areas. One year after the spill, an inverse correlation existed between oil on the sediment surface and plant growth. Three and one-half years after the spill, the straight chain hydrocarbons were gone from the sediments--branch-chained compounds had decreased and eventually disappeared by year 4, apparently metabolized by bacteria. One-third of the oil had a residence time in the sediments of over 5 years. The sediments were not totally recolonized after 8 years, with aromatics and naphthalenes persisting throughout the study.

Recolonization by burrowing animals increased exchange between sediment oil and the water, thus speeding up the oil clean-up. Though the first colonizers were killed by high oil levels, they made the sediment clean enough to allow more animals to survive. No food chain magnification was found; however, most animals got oil in their systems through feeding (10-several hundred ppm) rather than through equilibrium with the water (2 ppb).
KEY WORDS: OILS, MARSH, MASSACHUSETTS

Canter, L.W., E.H. Klehr, J.W. Laguros, L.E. Streebin, G.D. Miller, and D.R. Cornel. 1977.

AN ASSESSMENT OF PROBLEMS ASSOCIATED WITH EVALUATING THE PHYSICAL, CHEMICAL AND BIOLOGICAL IMPACTS OF DISCHARGING FILL MATERIAL.
Tech. Rep. D-77-29. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 121 pp. + Append.

This is a review article, one section of which presents an overview of the biological impacts of filling with dredged material. Included are discussions of loss of habitat, flow regime alterations, increases in turbidity, chemical pollutants and their effects on fish and the benthos, etc. An extensive bibliography is presented, and the authors highlight the biological effects on the biota with statements from the literature.
KEY WORDS: REVIEW

Carey, A.G., Jr. 1969.

ZINC-65 IN ECHINODERMS AND SEDIMENTS IN THE MARINE ENVIRONMENT OFF OREGON.
Pages 380-388 in D.J. Nelson and F.C. Evans, eds. Proc. 2nd Natl. Symp. Radioecology, Ann Arbor, Mich.

In samplings of large macrobenthos taken in offshore transects, it was found that zinc-65 is the most important gamma-emitter discharged into the Columbia River. Surface-living organisms receive more radiozinc in their food supply than organisms in the sediment or those feeding on other benthic organisms. Zinc is also more concentrated in surface sediments than at greater depths. Undetectable levels of zinc-65 in sediments were concentrated to significant levels by a brittle star and then transferred to starfish which prey on them. The specific activity of zinc-65 is dependent on the mode of feeding of organisms. Selective deposit feeders eating organics from the sediment surface contained more Zn than burrowing non-selective deposit feeders.

KEY WORDS: ECHINODERM, RADIONUCLIDE, ZINC, BIOACCUMULATION, OREGON, WASHINGTON

Chapman, P.M., L.M. Churchland, P.A. Thompson, and E. Michnowski. 1979.

HEAVY METAL STUDIES WITH OLIGOCHAETES.
Pages 477-502 in R.O. Brinkhaus and D.G. Cook, eds. Aquatic Oligochaete Biology. Plenum Press, New York.

Studies suggest that oligochaetes are among the benthic invertebrates most tolerant to heavy metals. This paper reviews the literature on this subject. Oligochaetes withstood sediment loads of Cd, Zn and Cr that killed most other benthos. Cu can be toxic to many oligochaetes at 1 mg/l or less. Toxicity is dependent on hardness and alkalinity of the water for Cu, Cr, Cd, Ni and Zn (not Hg).

In a recent study conducted over a year with monthly sampling for Cu, Zn, Pb, Fe, Mn, Ni, Co, Cd, and Hg, there was no seasonal variability in tissue metal levels. Tissue metal levels can only be determined accurately if preservatives are not used and a correction is made for gut sediment metal levels. Heavy metals were mainly available through the organic fraction of the sediment. Accumulation rates are variable and may reflect local differences in biologically available metals. Oligochaetes may be able to regulate tissue metal levels, thus complicating the interpretation of bioaccumulation data. The actual route of accumulation, whether through sediment, bacteria or interstitial water, has not been determined. Oligochaetes may provide metals for animals higher in the food chain by becoming prey or by releasing metals from the sediment (bioturbation).

KEY WORDS: REVIEW, OLIGOCHAETE, HEAVY METALS

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Chen, K.Y., S.K. Gupta, A.Z. Syeip, J.C.S. Lu, M. Knezevic, and W.W. Choi. 1976.

RESEARCH STUDY ON THE EFFECTS OF DISPERSION, SETTLING, AND RESEDIMENTATION ON MIGRATION OF CHEMICAL CONSTITUENTS DURING OPEN-WATER DISPOSAL OF DREDGED MATERIALS.
Contract Rep. D-76-1. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 221 pp.

One of the papers in the U.S. Army Corps of Engineers' Dredged Material Research Program (DMRP) series, this report deals with the possibility of release of toxic materials during dredging. The report presents data obtained using sediment from one of the country's most polluted harbors--Los Angeles. In the laboratory, oxygen-free, double-distilled water was added to sediment samples in a 1:5 sediment to water ratio under either aerobic (bubbled with air) or anaerobic (bubbled with N_2) conditions. The same was done with seawater. The authors found that during the first hour of treatment, there is a "sudden release" of trace metals to seawater but that this is followed by subsequent removal from solution. In the long term, the direction of exchange of the various constituents is controlled by the redox conditions in the overlying water. The amount of flux is controlled chiefly by the type of sediment.

After 3 months under experimental conditions, the amounts of trace metals in the interfacial waters were at the sub-ppb to ppb range. The same was true of nutrients. The amount of soluble chlorinated hydrocarbons was not detectable. Only under oxidizing conditions were amounts of Cd, Cu and Pb released, and then only at sub-ppb to ppb levels. There was little change in the amounts of Hg, even under oxidizing conditions, and there was no increase in Cr because of the slow rate of oxidation from the CrIII to the CrIV state.

The authors point out that the only problem which they can foresee in dredging these sediments is that H_2S may be released to the water column under reducing conditions. Finally, the authors point out the need to establish appropriate numerical values based upon bioassay studies, rather than simply the amounts of chemical constituents in solution. They also suggest that trace metals are more of a problem when associated with organics because of possible incorporation into the food web.

KEY WORDS: DREDGING, METALS, CHLORINATED HYDROCARBONS, OILS

Chen, K.Y., J.L. Mang, R. Eichenberger, and R.E. Hoeppel. 1978.

CONFINED DISPOSAL AREA EFFLUENT AND LEACHATE CONTROL (LABORATORY AND FIELD INVESTIGATIONS).
Tech. Rep. DS-78-7. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 94 pp.

This is one of a series of systematic reports of work done in the U.S. Army Corps of Engineers Dredged Material Research Project (DMRP) series. In it, the authors synthesize results of work involving release of contaminants from spoil material, including oil and grease, heavy metals and chlorinated hydrocarbons. They report that, in general, oils and greases have a high affinity for solids and that the aromatic fraction, which is the most toxic, is generally not detectable at effluent streams from disposal sites. Further, problems to aquatic life from PCB's, pesticides and other chlorinated hydrocarbons are not due to the soluble fractions as much as they are due to the fractions which are strongly adsorbed to sediment particles and organics, particularly fulvic acid. Also, metals are usually precipitated with suspended solids, but under oxidizing conditions may go into solution and therefore come off into an effluent stream. Though values of contaminants in effluents were often greater than EPA and state standards, most containment areas showed excellent removal capacities. The authors do point out, however, that a high concentration of effluent solid phase metals pose a potentially adverse impact on the receiving waters. Such conditions may pose problems due to possible biological uptake and subsequent biomagnification in the aquatic food chain.

KEY WORDS: OILS, METALS, BIOCIDES, DREDGED MATERIAL

Cherry, D.S., and R.K. Guthrie. 1979.

THE UPTAKE OF CHEMICAL ELEMENTS FROM COAL ASH AND SETTLING BASIN EFFLUENT BY PRIMARY PRODUCERS. II. RELATIONS BETWEEN CONCENTRATIONS IN ASH DEPOSITS AND TISSUES OF GRASSES GROWING ON THE ASH.
Sci. Total Environ. 13:27-31.

Using neutron activation analysis, it was found that metal elements from coal ash are taken up by nutgrass and broom sedge growing in the drainage system of a coal ash basin. Mercury and zinc, and to a lesser degree, arsenic and copper, were concentrated by plants growing in leaching pools to a level exceeding the concentration in the sediment. All elements tested (Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Se, Sr, Ti, and Zn) were biomagnified above the water concentration.

Bioaccumulation in the leaves and fruit of these plants provides a concentrated source of potentially toxic chemical elements for passage to animals which consume these plants. These metals may also enter food webs by leaching from the ash into the water source.

KEY WORDS: METALS, BIOACCUMULATION, PLANTS

Courtney, W.A.M., and G.R.W. Denton. 1976.

PERSISTENCE OF POLYCHLORINATED BIPHENYLS IN THE HARD-CLAM (*MERCENARIA MERCENARIA*) AND THE EFFECT UPON THE DISTRIBUTION OF THESE POLLUTANTS IN THE ESTUARINE ENVIRONMENT.
Environ. Pollut. 10:55-64.

Hard clams, *Mercenaria mercenaria*, were exposed to suspensions of PCB-treated alumina particles in aquaria to determine: 1) uptake and internal concentrations of the PCB, and 2) depuration rates of PCB. The PCB used was Aroclor 1254 at two concentrations: 1.25 ppb and 12.5 ppb. The particle size of the alumina was not given, but 500 mg of PCB-treated alumina were added to each of six aquaria, each containing five clams which were held on glass rods. They were allowed to filter for 5 hours and then polystyrene foam and activated charcoal particles were added for the sixth hour to remove excess PCB-alumina. These 6-hour cycles continued for 21 days. Feces and animals were collected and analyzed periodically via gas chromatography through the end of the 3-week period. Another group of clams, from mud in the Southhampton area, were also analyzed for PCB content as a comparison.

Visceral mass was found to concentrate 1.4-5.3X the amount of PCB's as the foot. The tissue concentration factor was greater at the lower dosage (1.25 ppb) than at the higher dosage (12.5 ppb) of the PCB. For example, the visceral mass PCB concentration factor over the ambient of 1.25 ppb was 38X for 3 days and 1225X for 21 days. At the ambient concentration of 12.5 ppb, the factors were 84X for 3 days and 726X for 21 days. Feces obtained from living clams which had been subjected to the alumina regime indicated very slow losses of PCB's during 6 months of depuration. The mud group of clams also demonstrated higher PCB concentrations in visceral mass over the foot (about 2X).

In both of the studies (alumina particles and mud), the feces contained higher chlorinated PCB isomers than those in the clam tissues, which indicated to the authors a preferential accumulation of early eluting peaks in the clams. In this respect, the authors suggest that the clams may exert both a quantitative as well as a qualitative effect upon the distribution of PCB's in the ecosystem.

KEY WORDS: PCB, MOLLUSKS, ESTUARIES

Cross, F.A., J.M. Dean, and C.F. Osterberg. 1967.

THE EFFECT OF TEMPERATURE, SEDIMENT, AND FEEDING ON THE BEHAVIOR OF FOUR RADIONUCLIDES IN A MARINE BENTHIC AMPHIPOD.
Pages 450-461 *in* D.J. Nelson and F.J. Evans, eds. Proc. 2nd Natl. Symp. Radioecology. Ann Arbor, Mich.

Laboratory studies were conducted to determine the effects of temperature, feeding and presence of sediments on the behavior of zinc-65 in a species of gammarid amphipod (*Anonyx* sp.). Accumulation and elimination rates of zinc-65 were temperature dependent, although the effect appeared to be minimal within this organism's seasonal temperature range. There was no interaction between temperature and sediment presence on elimination rates. Individual differences in zinc-65 accumulation rates had a range of 14-19%. Elimination rates of zinc-65 were increased in the presence of sediment and were significantly greater (by an approximate factor of 3) in feeding than in non-feeding amphipods. Zinc-65 is the only element significantly retained by *Anonyx* fed *Artemia* labeled with zinc-65, cerium-144, scandium-46, and chromium-51. It retains 55% of the Zn. Zinc-65 loss during molting depended upon whether the zinc had been accumulated from food or from water. When uptake was from water, approximately 20% of the zinc-65 body burden was lost with the cast exoskeleton, whereas only 2% was lost when zinc-65 was accumulated from food.

KEY WORDS: AMPHIPOD, RADIONUCLIDE, ZINC

Davis, P.H., and R.B. Spies. 1980.

INFAUNAL BENTHOS OF A NATURAL PETROLEUM SEEP: A STUDY OF COMMUNITY STRUCTURE.
Mar. Biol. 59:31-41.

Infaunal benthic invertebrates were collected at a natural petroleum seep and at a nearby area with no oil in the sediments and compared. Both sites had 72% of their populations in common, representing over 90% of the individuals. This strongly suggests that the two sites are part of the same community. At the petroleum seep there were higher densities of individuals in many populations, but no large difference in diversity. It was hypothesized that this was due to increased ATP levels from the oil, which was used by bacteria, thus providing a food source. Surface deposit feeding species were in a much greater proportion to total species at the oil seep, while the non-seep site had more subsurface deposit feeders. The authors explain this through a rich microbial flora in surface sediments and an increased toxicity in sub-surface sediments for the oil seep region. The authors conclude that in this case, oil is more of a "trophic enrichment" rather than chronic pollution.

KEY WORDS: OILS, BENTHOS, CALIFORNIA, SEEPAGE

Dayal, R.A., A. Okubo, I.W. Duedall, and A. Ramamoorthy. 1979.

RADIONUCLIDE REDISTRIBUTION MECHANISMS AT THE 2800 M ATLANTIC NUCLEAR WASTE DISPOSAL SITE.
Deep-Sea Res. 26(A):1329-1345.

Box cores were taken at 2800-m depth at an abandoned nuclear waste disposal site in the Atlantic. Radioactive products, cesium-134 and cesium-137, were found in sediments near cannisters holding the waste. Since the amount of these materials in the sediment was about twice the background level, the authors are fairly certain that the cannisters were the source. X-ray photos showed a "bioturbation structure" in surface and deeper sections of the cores. Upon close inspection, these appeared to be burrows. Though no biological work was done here, it is implied that these were worm (polychaete) tubes. Older photos (taken 5 years and 1 year before this study) of the same site indicated large numbers of organisms in the sediment of an adjacent area.

The authors worked out a model which estimates the mixing rate at which the radioactive material is disturbed in the sediments. Only vertical distribution is considered, however. Observations and calculations suggested that bioturbation was the dominant mechanism by which the cesium-134 and cesium-137 were transported in the sediment and to the overlying water. Calculations indicated that 0.3% of the total cesium-137 released from the canister over 15 years had leached into the water column.

KEY WORDS: BIOTURBATION, POLYCHAETE, RADIONUCLIDES, DEEP SEA, METALS

DeLaune, R.D., W.H. Patrick, and R.J. Buresh. 1979.

EFFECT OF CRUDE OIL ON A LOUISIANA SPARTINA ALTERNIFLORA SALT MARSH.
Environ. Pollut. 20:21-31.

Metal cylinders were placed around grasses in a marsh. Oil was poured in and was allowed to stand for 6 months. The grass was then harvested and analyzed. Spartina alterniflora can tolerate a large amount of oil without a short-term decrease in above ground biomass. Second year growth (number of new shoots and stem density) was not affected by the oil unless oil was on new or growing blades.

Biological reduction of nitrate, manganese, iron and sulfate and the production of methane and ammonium in stirred sediments were not affected by up to 10% oil (on a soil-weight basis). Oil does not inhibit anaerobic reduction of sediments, nor does it inhibit transport of atmospheric oxygen to the roots. It is usually adsorbed onto dead plants and detritus, but usually is not around long enough to be a good energy source for bacteria.

KEY WORDS: OILS, GRASS, MARSH, LOUISIANA

DePinto, J.V., T.C. Young, and S.C. Martin. 1981.

AQUATIC SEDIMENTS.
J. Water Pollut. Control Fed. 53(6):999-1007.

This is a review paper of recent literature regarding analytical and sampling methods, heavy metals, organics, nutrients, biological activity and modelling. Some of the papers referenced deal with sediment pollutants and the biota.

KEY WORDS: REVIEW, METALS, OILS

Dicks, B. 1976.

THE EFFECTS OF REFINERY EFFLUENTS: THE CASE HISTORY OF A SALTMARSH.
Pages 227-245 in J.M. Baker, ed. Marine Ecology and Oil Pollution. John Wiley & Sons, New York.

The recolonization of a saltmarsh severely damaged and almost denuded by refinery effluent is traced. Some effects of oil on saltmarsh vegetation are:

1. High affinity between plant cuticle and hydrocarbons encourages adhesion of oil to vegetation
2. Oil obstructs leaf pores and prevents or restricts gas exchange to root and shoot
3. Oil films reduce light available for photosynthesis
4. Some cuticle-oil constituents are directly toxic to metabolic processes
5. Plants with large underground vegetative systems (perennials) survive oiling better than those without (annuals), since new growth can occur from these systems if shoots and leaves are destroyed.

The recolonization of the area appears to be associated with the improvement in effluent quality, recent mild weather and no oiling incidents for several

years. *Spartina* roots vegetatively, so an increased speed of recolonization may be observed if some grass is transplanted to bare mud.
KEY WORDS: MARSH, EFFLUENT, PLANTS

DiSalvo, L.H., H.E. Guard, N.D. Hirsch, and J. Ng. 1977.

ASSESSMENT AND SIGNIFICANCE OF SEDIMENT-ASSOCIATED OIL AND GREASE IN AQUATIC ENVIRONMENTS.
Tech. Rep. D-77-16, U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss. 148 pp.

This paper is essentially in two sections. The first is an extensive literature review on oil and grease determination in aquatic sediments and organisms. The second deals with accumulation of oil from sediments by selected fauna. The literature survey reviews knowledge on the content, levels, fate, effects and methods of analyzing oil and grease in sediments. The experimental section details preliminary experiments using actual contaminated, dredged material. This material was from the Duwamish River in Seattle, Oakland Bay, and New York Harbor. The initial concentration of oil and grease was greatest in the New York Harbor sediment (8,755 μg/g), followed by the Duwamish River sediment (1,224-2,301 μg/g) and finally by the Oakland sediment (748 μg/g). The sediment was extracted with hexane, followed by thin layer chromatography and sometimes by gas chromatography to isolate individual components. Control sediments were the same sediments which had been "cleaned" by extraction. The experimental animals were *Mytilus edulis*, *Hemigrapsis oregonensis*, *Acanthia spirata* (all marine) and *Corbicula* (freshwater). The purpose of the experiments was to see if any oil would be taken up from the contaminated sediments by the test organisms.

The results, although not conclusive, were suggestive. That is, those animals in the most contaminated sediment, the New York Harbor material, did generally show increased levels of oil over controls. Those in Duwamish and Oakland sediment showed no difference from controls. However, there were a few problems in terms of experimental design. For example, the use of "cleaned" (extracted) sediment as controls, rather than known clean sediment from a natural area, might have affected the results. The authors point out that some of the controls died during the experiments, perhaps as a result of residual contamination. Further, it is not clear whether the effects noted are due only to oils. That is, there might have been other entities in the sediments such as metals and pesticides. (The latter can be extracted with hexane and, hence, can show up as part of the oil and grease total).
KEY WORDS: HYDROCARBONS, BIOACCUMULATION, REVIEW, OILS

Engler, R.M. 1979.

BIOACCUMULATION OF TOXIC SUBSTANCES FROM CONTAMINATED SEDIMENTS BY FISH AND BENTHIC ORGANISMS.
Pages 325-354 *in* S.A. Peterson and K.K. Randolph, eds. Management of Bottom Sediments Containing Toxic Substances. Proc. 4th U.S.-Japan Experts Meet., Tokyo. USEPA, Corvallis, Oreg. EPA 600-3-79-102.

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Different methods of dredging have different impacts. The author contends, however, that the indirect (long-term and sub-lethal) effects of most dredging and disposal are usually minimal. Most metals newly introduced into the water or resuspended by dredging are not taken up by animals, but eventually return to the sediment. For example, iron, a metal low in toxicity to animals, is the metal with the largest uptake by animals. Accumulation rates vary over a wide range of parameters, including the type of organism, exposure time and concentration, salinity, water hardness and temperature, though no constant correlations exist for all cases. Once contaminated, however, only a few species are able to depurate themselves of metals. A depuration gradient exists among the major metals: Zn is the most easily depurated, followed by Hg, Cu, Pb, Ni, Cd, As and finally Se, which is not depurated.

Hydrocarbons in the environment behave differently than heavy metals. Estuarine and freshwater animals can withstand very high hydrocarbon levels for long periods without much uptake. Once adsorbed onto sediments, most hydrocarbons do not become resuspended. Oily residues in the sediment, often containing toxic chemicals, are biodegraded only slowly. The author cites U.S. Army Corps of Engineers Dredged Material Research Reports (DMRP) which indicated that selected estuarine and freshwater organisms can withstand exposure to dredged material which is contaminated with thousands of parts per million oil and grease and experience only minor mortality for periods of up to 30 days.

Pesticides, like hydrocarbons, are strongly sorbed to particles in suspension or in sediment. Results of DMRP reports indicate that release of these water-insoluble compounds will not occur to an appreciable extent during dredged spoil disposal operations.

Field studies indicated differences between polluted and nonpolluted sites in selected areas of the country, but, according to the author, these differences were either insignificant or were not wholly caused by disposal operations.

KEY WORDS: REVIEW, DREDGING, METALS, PESTICIDES, HYDROCARBONS

Engler, R.M. 1981.

IMPACTS ASSOCIATED WITH THE DISCHARGE OF DREDGED MATERIAL: MANAGEMENT APPROACHES.
Environmental Laboratory, U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss. 51 pp.

With few exceptions, impacts of aquatic disposal of dredged material are mainly associated with the physical effects. Biochemical interactions are infrequent with no clear trends, and elevated uptake of toxic metals and hydrocarbons are usually negligible.

The most drastic biological impact occurs when dredged material is of a different sediment type than the place where it is dumped (e.g., mud on sand). Land-based dumping often changes the geochemistry of the dredged material, subsequently enhancing the release potential of chemical constituents.

The author contends that turbidity levels are never high enough to be harmful to animals except corals. Metal levels in the sediment cannot be compared with metal levels in animals. Levels in the sediment are not an important parameter in animal uptake of metals.

Highly contaminated dredged material can be disposed of in open water if the material is isolated from the biotic zone of the marine system.

KEY WORDS: REVIEW, DREDGING

Evans, D.R., and S.D. Rice. 1974.

EFFECTS OF OIL ON MARINE ECOSYSTEMS: A REVIEW FOR ADMINISTRATORS AND POLICY MAKERS.
Fish. Bull. 72(3):625-638.

Literature on the effects of oil on marine ecosystems is reviewed. The focus is on studies of crude oil, and the results are discussed with the purpose of providing summaries which can be used by administrators and policy makers. The article points out that most of the research has concentrated on acute toxic effects rather than chronic impacts. Papers are cited which indicate that hydrocarbons are generally associated with marine sediments for geologically long periods of time and that oil-polluted sediment generally contains lower percentages of heavy components than undiluted crude. A small percentage of oil in sediment rapidly oxidizes, but the bulk of the oil takes a long time to oxidize (most understandable, since a reducing milieu is often present). Papers are cited which discuss the accumulation of oil in the food web, sometimes at toxic levels. The latter may be due to the lipid-soluble nature of most hydrocarbon factions. The review is not too technical; however, it is a good source of general literature through the early 1970's.
KEY WORDS: REVIEW, OILS

Flatau, G., and M. Aubert. 1979.

ETUDE DE LA TOXICITE ET INDUITE DU CADMIUM MILIEU MARIN.
Rev. Int. Oceanogr. Med. 53:51-59.

Cadmium toxicity appeared in trophic chains. Acute toxicity was low, but concentration phenomena appeared rapidly. The presence of sediment (sand) seems to lower the concentration of cadmium in the annelids and the crustaceans. The concentration factor decreases from phytoplankton to fish.
KEY WORDS: CADMIUM, BIOACCUMULATION, FRANCE, METALS

Foerstner, U. 1980.

INORGANIC POLLUTANTS, PARTICULARLY HEAVY METAL IN ESTUARIES.
Pages 307-348 in E. Olausson and I. Cato, eds. Chemistry and Biochemistry of Estuaries. John Wiley & Sons Ltd., London.

The plethora of papers regarding heavy metal and radioactive contaminants is such that the author chose to review only "a few, but characteristic, examples." Included is a general worldwide survey of estuarine pollution by such metals as Hg, Cd and Zn. Sources of inorganic pollutants are discussed as well as candidates for some of the most polluted coastal and estuarine areas. Among areas discussed are Minamata Bay, Tokyo Bay, and Tokuyama Bay, Japan; the New York Bight, Chesapeake Bay and the California Coast, U.S.A. Others are Hong Kong Harbor, whose bottom supports little life, and the Kaohsiung Harbor in Taiwan, which is probably responsible for the decline of oyster culture along the entire southwest coast of the island within the decade between 1970-80. In Europe, the author's candidates for the five most contaminated areas are: Clyde Sea (Liverpool Bay), Thames Estuary, the German Bight, the Baltic Sea and the Rhine/Waal/Meuse/Scheldt estuarine system.

Mentioned briefly also are types and sources of radionuclides, as well as areas of radionuclide contamination. Among the areas cited are the Columbia River, U.S.A., the Cumberland Area, U.K., and the New York Bight, U.S.A., all of which are downstream from either nuclear power plants or reprocessing plants. Regarding bioaccumulation of metals and radionuclides, the author cites works which show the direct relationship between concentration of contaminants in the sediment and the amount of contaminants in animals and plants. Foremost among the latare primary consumers such as oysters and mussels. Examples of bioaccumulation are given from Norway, England and Australia, among other sites.

KEY WORDS: REVIEW, HEAVY METALS, RADIONUCLIDES, ESTUARIES

Fowler, S.W., and J.C. Guary. 1977.

HIGH ABSORPTION EFFICIENCY FOR INGESTED PLUTONIUM IN CRABS.
Nature 266:827-828.

Crabs were fed several radioactive worms and then allowed to depurate for a period of days to weeks. About 90% of the initial radioactive loss from the crabs was through defecation. After 3 weeks, the crabs still retained 12% of the (VI) state and 41% of the (IV) state of the plutonium. The hepatopancreas retained the greatest amount of plutonium (43-85%), followed by the shell (8-43%) and finally by the gill and muscle tissue (5-10%). The efficiency of plutonium uptake in invertebrates is several orders of magnitude greater than vertebrate uptake efficiency. This is most likely due to a different digestive physiology.

KEY WORDS: CRUSTACEAN, RADIONUCLIDES, PLUTONIUM, CRAB, METALS

Fowler, S.W., G.G. Polikarpov, D.L. Elder, P. Parsi, and J.P. Villeneuve. 1978.

POLYCHLORINATED BIPHENYLS: ACCUMULATION FROM CONTAMINATED SEDIMENTS AND WATER BY THE POLYCHAETE *NEREIS DIVERSICOLOR*.
Mar. Biol. 48:303-309.

In a series of laboratory experiments, it was found that uptake of PCB from sediments was dose-dependent, attaining equilibrium after 2 months. PCB elimination rates were concentration-dependent, with higher initial loss rates in the worms containing higher levels of PCB's. Accumulation of PCB's from water was much more rapid than from the sediment; however, compared to water, sediments contributed the bulk of the PCB's to the worm.

KEY WORDS: BIOACCUMULATION, PCB, POLYCHAETE

Frazier, J.M. 1972.

CURRENT STATUS OF KNOWLEDGE OF THE BIOLOGICAL EFFECTS OF HEAVY METALS IN THE CHESAPEAKE BAY.
Chesapeake Sci. 13(Suppl.):S149-S153.

Aspects of the pollution ecology of Chesapeake Bay as it pertains to heavy metals is the subject of this general article. The author notes the scanty understanding of chemical processes underlying the bioavailability of metals to organisms in the natural environment. Such processes include absorption, ion exchange, complex formation, chelation, flocculation, coprecipitation, and thermal input. The latter might increase desorption of metals from sediment, thus making them more available to the biota. The direct and indirect toxic effects of metals on food chains are discussed and the author also presents data from Chesapeake Bay studies on the level of metals in common commercial shellfish such as *Crassostrea virginica*, *Mercenaria mercenaria*, and *Mytilus edulis*. Though some data were available on fish and lower members of the food chain in the Bay, he concludes that the data are insufficient to predict effects on desirable estuarine biota. More studies are suggested.

KEY WORDS: ESTUARIES, METALS, BIOAVAILABILITY, CHESAPEAKE BAY, VIRGINIA

Frazier, J.M. 1976.

THE DYNAMICS OF METALS IN THE AMERICAN OYSTER, *CRASSOSTREA VIRGINICA*. II. ENVIRONMENTAL EFFECTS.
Chesapeake Sci. 17(3):188-197.

Field experiments were conducted on the dynamics of Mn, Fe, Zn, Cu and Cd in the shell and soft tissues of the American Oyster, *Crossostrea virginica*. The oysters were exposed via emplacement in plastic trays which were set out in metal-contaminated sediment in Cadle Creek, Maryland (off the Chesapeake Bay) from September 1972 until August 1973. A control group was placed in the Rhode River, Maryland. The latter is not industrialized and has a salinity regime of 2-13^{0}/oo, which is similar to the experimental area. Ten of the hatchery-reared oysters were taken each month from each site for laboratory analyses. Zn and Cu accumulated in soft tissues of the oysters and reached levels of 4,100 μg Zn/gm (dry wt) and 450 μg Cm/gm at Cadle Creek, compared to 1,700 μg Zn/gm and 60 μg Cu/gm at the control site. In general, the relative enhancement of metals in oyster tissues at the experimental site tended to reflect the pattern of metal contamination in the sediment there as opposed to the control site. The growth of oysters at the sites was identical; however, shells at Cadle Creek were significantly thinner (16%) than the control group. The authors attribute this to metal contamination, but acknowledge that it could have been caused by internal dissolution of $CaCo_3$ shell matrix during unfavorable environmental conditions; i.e., the shells would have remained closed for long periods of time. The rate of metal uptake by the soft tissues was greatest during the summer and fall.

The author points out that the availability of metals from the substrate to the biota is dependent upon the physical-chemical processes which control the exchange of adsorbed metals to the overlying water and to benthic biota. Unfortunately in this study, the exact nature of the sediment was not determined, but rather, sediments were sieved through a 202 μm mesh before sediment chemical analyses were made. This, however, does not detract from the validity of the tissue analyses.

KEY WORDS: OYSTERS, HEAVY METALS, ESTUARIES, MARYLAND, SHELLFISH

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Friant, S.L. 1979.

TRACE METAL CONCENTRATIONS IN SELECTED BIOLOGICAL, SEDIMENT, AND WATER COLUMN SAMPLES IN A NORTHERN NEW ENGLAND RIVER.
Water Air Soil Pollut. 11:455-465.

The author points out the need for baseline data, where this is feasible, since it is not always apparent in an ecological system whether variances in animal tissue concentration are due to specific biological habitats or is a function of individual species. This baseline study took place in the Kennebec River, Maine, before the operation of a paper mill upstream of the sampling sites. Sediments, plants, fish and mollusks were analyzed for heavy metals via wet digestion (modified for Hg) and atomic absorption spectrometry.

Metal concentrations in fish and muscle tissue (*Catostomus commersoni*, *Micropterus dolomieui*, *Lepomis gibbosus* and *Perca flavescens*) were very low. The soft tissue of the mollusks collected (*Elliptio complanata*, *Lampsilis radiata* and *Anadonta cataracta*) contained greater amounts of metals than the fish, as did the plants (*Potamogeton perfoliatus*, *P. alpinus*, *Vallisneria americana* and *Eleocharis* sp.). Apparently, however, these molluskan levels (e.g., 109-414 mg/kg Zn, 2.3-34.2 mg/kg Cu, <0.01-5.9 mg/kg Pb, etc.) are not high enough to be considered a hazard to the functioning of the animals. Sediment metal levels are within the ranges reported for unpolluted streams.

The author concludes that the mollusks may be good indicators of heavy metal pollution, since they apparently accumulate the metals. Plants, too, accumulate the metals from the sediment, and therefore, might also be useful as indicators.

KEY WORDS: FISH, RIVER, METALS, MOLLUSKS, PLANTS, MAINE

Fujiki, M. 1980a.

METHYLMERCURY ACCUMULATION IN PLANKTON AND FISH.
Pages 485-492 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

This article describes two experiments. In one experiment, groups of red sea bream, *Chrysophrys majior*, were placed in 4 one-thousand liter tanks of seawater: 1) seawater with 5.0 µg/l of methylmercury added directly; 2) clean seawater with contaminated prawns (*Penaeus japonicus*) at 0.133 µg methylmercury/g of wet tissue; 3) sediment from Minamata Bay with a methylmercury concentration of 0.015 mg of methylmercury/kg sediment; and 4) a control tank, with no added methylmercury. Ten fish were removed from each tank each day and homogenized to determine the tissue CH_3Hg content via gas chromatography. Fish did not take up CH_3Hg from the contaminated sediment (i.e., no different from control tank). The tank to which methylmercury was added directly to the water provided the most uptake by the fish (x=0.33 µgHg/g wet muscle), followed by the tank with the contaminated prawns (x=0.020 µg/g).

In another experiment, the diatom, *Skeletonema costatum*, the copepod, *Acartia clausi*, and the red sea bream were placed in tanks containing various amounts of inorganic mercury and methylmercury. The diatoms were reared in 0.5 µg/l of inorganic mercury and in 0.5 µg/l and 5.0 µg/l of methylmercury for 24 hours and then collected. The copepods were reared in 0.5 µg/l HgCl and 0.5 µg/l CH_3Hg for 24 hours and then collected. A third tank of copepods

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was fed the diatoms from the 5.0 μg/l tank and then collected after 4 days. The juvenile fish were fed both contaminated copepods and also contaminated brine shrimp for 10 days and then collected. Methylmercury was taken up by all species faster and in greater concentrations than inorganic mercury. Uptake through the food chain, however (i.e., diatom to copepod to fish), was low and the final fish tissue concentration after 10 days was the same as the copepods upon which the fish were feeding.

KEY WORDS: MERCURY, PHYTOPLANKTON, FISH, CRUSTACEAN, BIOACCUMULATION

Fujiki, M. 1980b.

THE POLLUTION OF MINAMATA BAY BY MERCURY AND MINAMATA DISEASE.
Pages 493-501 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

This study concerned mercury levels in shellfish and fish in the highly mercury-contaminated Minamata Bay in Japan. Data are presented which summarize values from 1959-1972. Some sediment within the bay contained as much as 700 ppm-900 ppm Hg (dry wt.) as a result of a vinyl chloride and acetaldehyde plant which discharged mercury wastes into the waters of this relatively enclosed bay until 1971. Minamata disease, which affects the central nervous system in humans, was first identified in 1953 and has resulted in 48 deaths plus numerous active cases as of 1971. Levels of Hg in fish and shellfish decreased during the period 1959-1972, possibly as a result of cessation of input by the plant into the bay. For example, 1959 values for two shellfish, *Hormomya mutabilis* (a rockdweller) and *Venue japonica* (a bottom dweller) were 108 ppm and 178 ppm, respectively. (It is not clear from the paper whether these are single or average values.) In general, levels decreased from the 30-50 ppm range to the 1-4 ppm range in shellfish and from the 20 ppm to 0.5 ppm range in fish over the 13-year period. Sediment mercury changes during that period were not discussed.

KEY WORDS: MERCURY, MINAMATA DISEASE, JAPAN

Fulk, R., D. Gruber, and R. Wullshlager. 1975.

LABORATORY STUDY OF THE RELEASE OF PESTICIDE AND PCB MATERIALS TO THE WATER COLUMN DURING DREDGING AND DISPOSAL OPERATIONS.
Contract Rep. D-75-6. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 27 pp.

Sediments from five areas (Calumet Harbor, Chicago; Fox River, Green Bay; Hope Bay, Fall River, Mass.; Tabbs Bay, Houston; Tennessee Chute, Memphis) were analyzed for PCB's and the pesticides aldrin, dieldrin, endrin, lindane, 2,4-D, DDT, DDD, DDE, and toxaphene. Aliquots of sediments were also agitated in water for 24 hours and the water was then analyzed for these same materials after centrifuging out the sediments. PCB's were recovered in 59/64 of the sediment samples. Of the pesticides, DDT and dieldrin were the most common. In the water column experiments, soluble pesticides were below detection limits. The only pesticides in the water column were associated with suspended solids. Factors affecting the release of pesticides and PCB's from sediments are: the amount of solids compared to the amount of water; concentration of the pollutant; particle size and organic content; and the amount of oil and grease (oil and grease are non-polar, as are many pesticides).

The authors concluded from this work, as well as from the literature, that adsorption of PCB's and pesticides occurs much easier than desorption. They postulated, therefore, that the transfer of PCB's and pesticides from the bottom material to the water column during dredging and disposal operations is not significant.

KEY WORDS: PESTICIDES, PCB, SPOIL CONTAINMENT

Gallagher, J.L., and P.L. Wolf. 1980.

FIELD BIOASSAYS FOR THE ROLE OF PLANTS AS VECTORS IN CONTAMINANT TRANSFER FROM DREDGED MATERIAL.
Pages 445-464 in R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

Field experiments were undertaken with marsh plants and sediments. The research was divided into two parts. The first study concerned the uptake of toxaphene by Spartina alterniflora. The second, and more complex experiment, was to evaluate the growth responses of several species of marsh plants to various contaminated sediments in two different marsh environments in Georgia and Oregon.

The first experiment, on toxaphene uptake, utilized 1 x 3 m plots (six reps) situated in a marsh on Sapelo Island, Georgia, so as to undergo the natural conditions (tidal cycles, wave action, etc.). Toxaphene was injected into the sediment of each treatment plot and the appearance of the pollutant in plant tissues was measured at intervals afterward. Toxaphene levels of 43 ppm occurred 1 month after injection and declined thereafter over a 4 month period. The authors hypothesized that the toxaphene was lost, not by leaching, but by decay and fragmentation of the tissues, based on live and dead tissue analyses. Hence, the toxaphene would be available to the food web.

The other, more diffuse experiment, took place both in Georgia and Oregon. Plastic buckets, drilled with holes to accommodate flushing, were filled with various contaminated sediments, planted with marsh grasses, and set out in marshes. Three contaminated sediments (pesticides, PCB's and heavy metals) and a control substrate were utilized. Six species of marsh plants (Spartina alterniflora, Spartina patens, Distichlis spicata and Salicornia virginica in Georgia; Carex lynbyei, Deschampsia cespitosa, D. spicata, and S. virginica in Oregon) were used, although the density of planting was not controlled and "depended on the species." The heavy metal sediment, from Bridgeport Harbor, Connecticut, was apparently extremely toxic, and the only plants which grew in it (poorly, it should be noted) were Salicornia virginica. Sediment cadmium content, for example, was over 42 mg/Kg, while background Georgia and Oregon marsh soils ranged from less than 0.01 mg/Kg to 0.54 mg/Kg. Likewise, chromium and copper levels were over 3,000 mg/Kg and 4,000 mg/Kg, respectively, while natural marsh soils ranged from 6.8-114 mg/Kg. The supposed pesticide-contaminated sediment was not contaminated; therefore, the plants experienced no growth difficulties. The PCB-contaminated sediment from the Hudson River, New York, caused less plant growth than controls during the course of a year.

The authors concluded that the second experiment was successful in that it enables one to predict whether a marsh can be established on top of contaminated spoil. It would appear, however, that such a broad approach is most useful for extremely contaminated sediments (i.e., an "all or (practically)

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none" response on the part of the plants). In the other cases, value judgements must be formulated to determine suitability of using dredged material which causes slightly or moderately stunted growth.

KEY WORDS: SALT MARSHES, TOXAPHENE, PCB, METALS, BIOASSAY

Gambrell, R.P., V.R. Collard, C.N. Reddy, and W.H. Patrick, Jr. 1977.

TRACE AND TOXIC METAL UPTAKE BY MARSH PLANTS AS AFFECTED BY Eh, pH, AND SALINITY.
Tech. Rep. D-77-40. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 141 pp.

Laboratory studies as well as greenhouse studies were undertaken with several wetland and marsh plants (*Distichlis spicata*, *Spartina alterniflora*, and *Spartina cynosuroides*) to determine the effect of uptake of heavy metals (Hg, Pb, Cu, Fe, Mn). Redox conditions and the pH were controlled. Using labeled mercury, the authors found that decreases in salinity and increases in pH tended to enhance its uptake by the plants. Zinc, on the other hand, was found to be taken up greater as the medium became more oxidized, while copper showed little variation in uptake due to variations in either pH or redox potential. Cadmium content in above-ground tissues was increased with increases in oxidation conditions in all species in both laboratory and greenhouse experiments.

Several important findings emerged from the studies. First, that the physicochemical conditions were important in the uptake of metals by the plants. Second, that species differences among the plants were important as well as species differences among the elements. The authors concluded that these effects should be considered in selecting "environmentally sound" methods and sites for disposal of metal-contaminated sediment.

KEY WORDS: PLANTS, REDOX, METALS, BIOACCUMULATION, pH

Gambrell, R.P., V. Collard, and W.H. Patrick. 1980.

CADMIUM UPTAKE BY MARSH PLANTS AS AFFECTED BY SEDIMENT PHYSICOCHEMICAL CONDITIONS.
Pages 424-443 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

Three marsh plants, *Spartina alterniflora*, *Spartina cynosuroides*, and *Distichlis spicata*, were utilized in experiments to determine the uptake of Cd from sediment under acid (pH=4.5) and base (pH=7.5) conditions and at both exodizing and reducing environments. Previous experiments have shown that significantly higher amounts of sediment-bound cadmium were released to the water column at low pH under oxidizing conditions. In these experiments, seedling marsh plants were grown in the laboratory and then transferred to a standard soil (1:4 water:soil ratio) to which 1 μg Cd/g of soil was added. Oxidizing conditions were established by bubbling air and reducing conditions were established by bubbling nitrogen gas through the water-soil mixture. Sediment pH was maintained by adding 2N HCl or NaOH as needed. After 2 weeks, the plants were harvested and the amounts of Cd were determined by atomic absorption spectrometry. As a check, some of the pots were labeled with cadmium-109. Those plants were later analyzed after harvest with radiotracer techniques.

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The *Spartinas* showed greatest uptake of Cd at low pH under oxidizing conditions at both low and medium salinity waters. In *Distichlis*, however, greatest uptake occurred at high pH under oxidizing conditions, also at both low and medium salinity waters. Greenhouse experiments were also conducted and demonstrated that those *Spartina* plants grown at low pH under oxidizing conditions in Cd-contaminated soil had significantly lower biomass than their counterparts grown in high pH under reducing conditions. The authors suggest that cadmium poisoning may have caused the lowered biomass, as other research has shown toxic effects from Cd at the levels reached in the greenhouse.

As a result of these studies, the authors suggest that Cd-contaminated spoil material which has been under reducing conditions should not be placed on upland sites where the potential for oxidation is great, and therefore, the possibility of cadmium uptake by plants would be great. Rather, such spoil might better be placed in open water under natural reducing conditions, provided that it is far enough away from valuable commercial or benthic resources.

KEY WORDS: CADMIUM, PLANTS, REDOX, BIOACCUMULATION, pH

Giblin, A.E., A. Bourg, I. Valiela, and J.M. Teal. 1980.

UPTAKE AND LOSSES OF HEAVY METALS IN SEWAGE SLUDGE BY A NEW ENGLAND SALT MARSH.
Am. J. Bot. 67(7):1059-1068.

For 7 years varying doses of fertilizer containing sewage sludge were added to experimental plots in the marsh. High marsh areas retained a significantly greater fraction of all added metals, except Mn, when compared to low marsh areas. The authors believe that the high marsh, being subjected to less flushing of ions than low marsh areas will, therefore, experience less flushing of ions than low marsh areas. Metals were found to have no effect on growth of the grasses within the plots. The dominant grasses, *Spartina patens* and *S. alterniflora*, contained elevated levels of Cd, Cr, Cu and Zn. Animals within the plots also showed elevated levels of metals. For example, the mussel, *Modiolus demissus*, had elevated levels of Cd, Cr and Cu, while the fiddler crab, *Uca pugnax*, had higher levels of Cd, Cu and Mn. The killifish, *Fundulus heteroclitus*, also experienced slight increases in metals content, although, as the paper points out, the fish roams a greater area than the other two species sampled and, hence, may ingest less from the experimental plots.

KEY WORDS: HEAVY METALS, SALT MARSH, MASSACHUSETTS

Giere, O. 1979.

THE IMPACT OF OIL POLLUTION ON INTERTIDAL MEIOFAUNA. FIELD STUDIES AFTER THE LA CORUNA SPILL, MAY, 1976.
Cah. Biol. Mar. 20:231-251.

Approximately 30,000 tons of Arabian light crude contaminated 350 km of coastline in northern Spain, affecting meiofauna in at least the top 140 cm of sediment. Initial mortality included all meiofauna (except some turbellarians), including most nematodes. There was a great variance in resistance to oil among taxonomic and trophic groups--even within the same genus. Nematodes

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were first to recolonize the spill area. After 1 year, abundance and diversity of fauna had increased in the spill area, indicating that regeneration was taking place. Besides reproduction of surviving animals, the author points out that regeneration can also take the form of recruitment of meiofauna from unpolluted areas.

The rate of purification of sediments is, by axiom, due largely to different wave exposure, grain size, drainage and oxygen supply (the higher the exposure, the faster the clean-up). Giere points out that this is not necessarily the case. The coarser the sediment, the faster and deeper the oil is incorporated into it. The oil is driven into deep, low oxygen sediments where breakdown is slower, rather than staying on the surface where the oil weathers most effectively or can be mechanically removed. An oil film also coats all sediment particles it passes, thus decreasing the permeability of the sediment, reducing nutrient flow, turbation and, consequently, oil breakdown. The author also points out that even if animals are resistant to toxic, water-soluble hydrocarbons, they will be killed by direct contact with the oil. Therefore, with much oil in the sediment, large mortalities may result.

KEY WORDS: OILS, MEIOFAUNA, SPAIN

Gilfillan, E.S., and J.H. Vandermeulen. 1978.

ALTERATIONS IN GROWTH AND PHYSIOLOGY OF SOFT-SHELL CLAMS, MYA ARENARIA, CHRONICALLY OILED WITH BUNKER C FROM CHEDABUCTO BAY, NOVA SCOTIA, 1970-1976.
J. Fish. Res. Board Can. 35:630-636.

Oiled and non-oiled populations of clams were compared. Oiled clams differed from unoiled clams in lower total numbers, fewer mature adults, a 1 to 2 year lag in tissue growth, a lower shell growth rate and a reduced carbon flux with a lower assimilation rate. The top 5 cm of sediment had been flushed free of oil since the spill in 1970, but oil was still found below 5 cm. Thus, young clams could settle and survive in a relatively oil-free environment, while older clams, which lie deeper in the substrate, were still stressed in heavily oiled layers. The result was that the recovery potential of *M. arenaria* in this oiled sediment is low and the populations remained under stress 6 years after the oil spill.

KEY WORDS: OILS, CLAM, CANADA, SHELLFISH

Grant, B.F. 1976.

ENDRIN TOXICITY AND DISTRIBUTION IN FRESHWATER: A REVIEW.
Bull. Environ. Contam. Toxicol. 15(3):283-290.

This is a review paper which concerns the pesticide, endrin, generally in terms of acute and chronic toxicity studies. Forty-nine papers published between 1961-73 are reviewed here. Most of the papers deal with laboratory toxicology studies on trout and goldfish. The compound is known to affect growth, gonad development, thyroid activity, body fat content, and behavior. Several environmental studies were cited, however, which suggested that mud sediment may have such a strong affinity for the pesticide that there would be little long-term harm to the biota. Further, there may be populations of fish (e.g., mosquitofish) which have become resistant to the effects of endrin.

KEY WORDS: REVIEW, ENDRIN, BIOCIDES

Guary, J.C., M. Masson, and A. Fraizier. 1976.

IN SITU PRELIMINARY STUDY OF PLUTONIUM DISTRIBUTION IN DIFFERENT TISSUES AND *ORGANS* OF *CANCER PAGURUS* (DRUSTACEA; DECAPODA) AND *PLEURONECTES PLATESSA* (PISCES; *PLEURONECTIDAE*).
Mar. Biol. 36:13-17.

Plutonium is adsorbed from sea water to the gills and exoskeleton of the crab, *Cancer pagurus*. In the plaice, *Pleuronectes platessa*, only the gut strongly accumulated plutonium, which indicated contamination by feeding. Since the plaice is a flatfish, it is possible that sediments might be accidentally ingested while feeding is accomplished. The edible parts of these two marine species did not show significant plutonium concentration, and, therefore, do not constitute an important source of contamination by environmental plutonium.

KEY WORDS: RADIONUCLIDES, CRUSTACEAN, FISH, FRANCE, PLUTONIUM, CRAB, METALS

Hansen, D.J., A.J. Wilson, D.R. Nimmo, S.C. Schimmel, L.H. Bahner, and R.J. Huggett. 1976.

KEPONE: HAZARD TO AQUATIC ORGANISMS.
Science 193:158.

Kepone is very bioaccumulative and persists in estuarine organisms. Oysters, grass shrimp and fish have concentrated kepone to 425-20,000 times the level of the surrounding water.

Oysters were found to depurate 90% of accumulated kepone within 4 days, while fish could only depurate 40-50% of the kepone in 3 weeks. Ninety-six-hour tests underestimate long-term deleterious effects of Kepone on organisms.

KEY WORDS: KEPONE, BIOACCUMULATION, BIOCIDES

Hauschild, W.L. 1980.

TRANSPORT, ACCUMULATION AND DISTRIBUTION INTER-RELATIONSHIPS BETWEEN HANFORD-REACTORS' RADIONUCLIDES AND COLUMBIA RIVER SEDIMENT.
Pages 95-117 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 1. Ann Arbor Science, Ann Arbor, Mich.

The Columbia River received low-level nuclear waste from the Hanford nuclear reactors in Oregon between 1944-1971. The wastes were derived primarily from neutron activation of chemical constituents in river water used to cool the reactor. The long-lived radionuclides ultimately became tied up in the sediment of the streambed from the reactor site all the way down to the Pacific Ocean. This paper reviews data collected in studies done in the 1960's which documented the levels of a number of radionuclides (chromium-51, zinc-65, scandium-46, iron-59, manganese-54, antimony-124, cobalt-58, and cobalt-60) at a number of locations in the Columbia River, as well as in the Snake and Willamette Rivers, which enter the Columbia.

Sediment characteristics were described and total discharges of the radionuclides were calculated. The total amount of radionuclides in the river sediment between the reactors and the ocean were estimated at 28,900 Ci

(8,700 Ci in the estuary and 20,200 Ci in the riverbed). In sandy sediments at some locations in the river, the radionuclides are distributed equally to a depth of more than 1.5 m. In fine sediments, radionuclide levels were highest just at or near the surface of the sediment; levels were usually insignificant at a depth of 0.3 m or more. The author speculated that the riverbed, rather than the estuary, is the principal source of particulate radionuclides to the ocean each June (the rainy season).

KEY WORDS: RADIONUCLIDES, NUCLEAR REACTORS, OREGON, METALS

Hennig, H.F-K.O., and A.H. Fricke. 1980.

RECOVERY POTENTIAL AND CHRONIC OIL POLLUTION ON THE SOUTH AFRICAN COAST.
Mar. Pollut. Bull. 11:301-302.

When first washed ashore, an oil-water emulsion covered 85% of the beach. The oil was buried by later tides. During a beach erosion cycle, oil was exposed and refloated, reducing concentrations by 35%. After reburying and dilution and weathering 6 months after the spill, stress decreased enough for recolonization and quickly returned to prespill meiofaunal levels. Nine months later the experiment was terminated when another oil spill washed ashore.

Southwestern Cape beaches were classified as chronically polluted. It takes 6-8 months for a beach to recover from an oil spill, but with 678 tons of oil dumped on South African beaches every year, there is never enough time for a full recovery. Recovery of these areas was so fast because the beach is exposed to much wave action, which tends to cleanse the sediments.

KEY WORDS: OILS, SOUTH AFRICA, BEACHES

Hildebrand, S.G., R.H. Strand, and J.W. Huckabee. 1980.

MERCURY ACCUMULATION IN FISH AND INVERTEBRATES OF THE NORTH FORK, HOLSTON RIVER, VIRGINIA AND TENNESSEE.
J. Environ. Qual. 9(3):393-400.

Rock Bass (*Ambloplites rupestris*) and hog sucker (*Hypentelium nigricans*) and benthic invertebrates were collected from stations above and below a formerly active chloralkali plant. Axial mussle (fish) or whole animal (invertebrates) was analyzed for total mercury by flameless atomic absorption spectrometry and for methylmercury by gas chromatography. The relation of total mercury concentration to fish weight and factors affecting mercury concentration in fish and invertebrates were examined through regression analysis. Total mercury concentration in fish and invertebrates decreased with distance below the plant. Hg concentration in fish remained above the 1.0 μg/g FDA "action level" for a considerable distance (13 km for the rock bass and 43 km for the hog sucker).

Significant linear regressions of total mercury concentration on fish weight were observed for a number of the samples analyzed. Mercury in the methyl form comprised 91.7% of total mercury in fish analyzed, while about 50% of the mercury in invertebrates was methylmercury. It was found that invertebrates obtained 94% of their mercury from the sediment and 3% from the water column. Rock bass, in turn, obtained 72% of their mercury from the benthos, while the hog sucker obtained 68% from benthos, based upon the regression analyses.

KEY WORDS: MERCURY, FISH, INVERTEBRATES, TENNESSEE, VIRGINIA

Hoeppel, R.E., T.E. Myers, and R.M. Engler. 1978.

PHYSICAL AND CHEMICAL CHARACTERIZATIONS OF DREDGED MATERIAL INFLUENTS AND EFFLUENTS IN CONFINED LAND DISPOSAL AREAS.
Tech. Rep. D-78-24. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 195 pp. + Append.

This study involved the assessment of nine confined disposal areas for mobility of heavy metals, oil and grease, pesticides and PCB's. The dredged material came from freshwater, brackish water and marine areas. DDE was generally found to be associated with fine clay-sized particles, whereas DDD and DDT were associated with larger particle sizes. Mercury was also associated with fine particles. High PCB content always was associated with high levels of suspended solids. Therefore, because of this adsorption, flocculants removed 99.8% of the PCB's in test aquaria. The pH of the sediment interstitial water is important in the mobility of metals. For example, while Cd is usually associated with organic-sulfide complexes, oxidizing conditions in land containment areas were found to shift Cd to more available phases.

The authors recommended that an extra effort should be directed toward removal of fines, because ingestion of these fines by organisms could result in release of mercury. Further, if Cd, Hg, or DDD are major constituents of material to be contained, efforts should be made to use flocculants.

KEY WORDS: METALS, PESTICIDES, SPOIL CONTAINMENT

Horii, S., T. Yamagishi, Y. Miyazaki S. Kaneko, and H. Murakami. 1980.

DISTRIBUTION OF HEAVY METALS IN THE SHORT-NECKED CLAM AND IN THE SUBSTRATE IN THE BAY OF TOKYO ('78-'79) (Abstract only. Transl. from Japanese.)
Pages 156-160 in Tokyo Metropolitan Hygiene Research Institute Annual Report, No. 31-1.

During this study, 108 samples were examined. The total mean values (ppm) found in the short-necked clam were the following: Zn-23; As-1.52; Cu-1.1; Co-0.14; Pb-0.13; Hg-0.104; Cd-0.04. The content of Cd in the short-necked clam was high in the area of Ooi. The content of Co in the short-necked clam was high in the areas of Tamizu and Kisarazu. The total mean values (ppm) found in the substrate were the following: Zn-56; Co-4.82; Pb-4.33; As-3.03; Hg-0.122; Cd-0.55. The amounts of Pb, Co, Zn, and Cd were high in the substrate of the Ooi area.

KEY WORDS: MOLLUSKS, HEAVY METALS, JAPAN

Huggett, R.J., M.M. Nichols, and M.E. Bender. 1980.

KEPONE CONTAMINATION OF THE JAMES RIVER ESTUARY.
Pages 33-53 in R.A. Baker, ed. Contaminants and Sediments. Vol. 1. Ann Arbor Science, Ann Arbor, Mich.

Water, sewage and leachates have endowed an area of the James River with about 0.5 metric tons of kepone. A plant at Hopewell, Virginia, operated from 1966-1975 and is thought to be responsible for most of the kepone in that environment. Kepone is decachlorooctahydro-1, 3, 4-metheno-2H-cyclobuta (cd) pentalene.

The authors include a map showing the extent of contamination along the estuary and they cite research which indicates that all levels of the food chain have been contaminated with kepone. For example, phytoplankton averaged 1.3 μg/g (which is about 10^4 times the concentration in the water column); zooplankton averaged 4.8 μg/g; the hard clam, Mercenaria mercenaria, 0.09 μg/g; and the channel catfish, Ictalurus punctatus, 0.04 μg/g. It was found that the residue in long-term residents such as catfish, hogchokers and white perch did not fluctuate seasonally. Migratory and seasonal visitors like croaker, spot, bluefish and shad exhibited larger concentrations with longer stays in the estuary.

Though chronic toxic effects had not been noted, the authors point out that the kepone is associated with find grained sediment and organics, and there was no evidence that it either breaks down naturally or via organismal metabolism. They postulate that assimilation pathways are either direct from the sediment to organism (e.g., suspension feeders and bottom infauna) or indirect through the food chain.

KEY WORDS: KEPONE, FISH, RIVER, ESTUARIES, CRUSTACEAN, VIRGINIA, BIOCIDES, BIOACCUMULATION

Hunter, R.G., J.H. Carroll, and J.C. Randolph. 1980a.

ORGANOCHLORINE RESIDUES IN THE FISH OF LAKE TEXOMA, OCTOBER 1979.
Pestic. Monit. J. 14(3):102-107.

Eleven species of fish from Lake Texoma were examined for residues of common pesticides. PCB's were found in most species at levels up to 1,100 ng/g of fish tissue. There was no difference between levels in herbivores and detritivores, but levels were higher in carnivores. O, P'-DDT and P, P'-TDE were found in herbivores (though rarely) and in detritivores at levels up to 17 and 36 ng/g, respectively, but were not found in carnivores. P, P'-DDT was present in detritivores and carnivores up to 410 ng/g. Heptachlor was not found in carnivores, but was in concentrations as high as 37 ng/g in the other two classes.

Chlordane was detected in all trophic levels up to concentrations of 24 ng/g. Dieldrin was present in detritivores and carnivores up to 144 ng/g. Mirex, endrin and heptachlor epoxide were present only at low levels. No correlation was found between organochlorine concentrations and geographical location of the sample. However, significant differences were found between trophic levels ($p=0.05$).

KEY WORDS: FISH, PESTICIDES, OKLAHOMA, TEXAS

Hunter, R.G., J.C. Randolph, and J.H. Carroll. 1980b.

POLYCHLORINATED BIPHENYLS IN THE SEDIMENTS AND FISH OF AN OKLAHOMA STREAM.
Environ. Pollut. (Ser. B.) 1:233-240.

The PCB source of Pryor Creek, Oklahoma, is a paper recycling plant. PCB's enter the stream as runoff due to rainfall erosion of a mixture of clay and paper pulp containing PCB's. The PCB's probably enter the system in association with particulate matter, since no PCB's have been detected in the water column. Further, PCB levels in sediments were greatest at areas of high sediment deposition. Concentrations of PCB's were significantly greater in detritivores than in either omnivores or predators. Carp in this creek averaged 40 times the PCB levels found in carp in the rest of the state. The maximum allowable level of PCB's, 5 mg/g, was exceeded by many of the carp and most of the carpsuckers. PCB concentrations were significantly correlated with either body weight, lipid content, or both.

KEY WORDS: PCB, FISH, OKLAHOMA

Hunter, R.G., J.H. Carroll, and J.S. Butler. 1981.

THE RELATIONSHIP OF TROPHIC LEVELS TO ARSENIC BURDEN IN FISH OF A SOUTHERN GREAT PLAINS LAKE.
J. Freshw. Ecol. 1(1):121-127.

Arsenic content was analyzed in 87 fish from three trophic levels in Lake Texoma. Sediment samples were compared to body burdens of bottom-feeding fish. Arsenic content for all fish ranged from 0.1-34.0 μg/g wet weight. The highest concentrations were in planktivores. The mean value in all fish was 2 μg/g. Body burdens of arsenic were found to be limited by excretion and were not correlated to body weight, length, or sample location. Concentrations of arsenic were significantly greater ($p=0.05$) in planktivores than in omnivores; however, it did not vary significantly between piscivores and either planktivores or omnivores. The authors suggest that planktivorous species may be able to bioconcentrate arsenic, while omnivorous and piscivorous fish biomagnify arsenic through their diet.

KEY WORDS: ARSENIC, BIOACCUMULATION, OKLAHOMA, TEXAS

Ichikuni, M. 1979.

CHEMICAL COMPOSITION OF PRINCE FEATHER LEAVES: A GEOCHEMICAL INDICATOR OF ORGANIC MATTER IN THE FLUVIAL SEDIMENT (Abstract only. Transl. from Japanese.)
Geochemistry. 13:13-17.

A high manganese content found in some of the samples of prince feather leaves, *Polygonum orientale*, revealed the availability of the element in the reducing environment of the swampy ground on which the plant grows. Under reducing conditions, Mn is released as a divalent ion and is taken up by plants. Organic matter also behaves as a chelating agent toward many heavy metal ions. Accumulation of heavy metals in the soil is indicated by often high levels of copper and zinc in manganese-enriched leaf samples.

KEY WORDS: HEAVY METALS, PLANTS, JAPAN, MANGANESE

Ishikawa, T., and Y. Ikegaki. 1980.

CONTROL OF MERCURY POLLUTION IN JAPAN AND THE MINAMATA BAY CLEANUP.
J. Water Pollut. Control Fed. 52(5):1013-1018.

This paper reviews past and ongoing measures to clean up Minamata Bay in Japan by removing and containing mercury-contaminated sediment. The Chisso Company operated from 1932-1971 using a mercury catalyst in the manufacture of vinyl chloride and acetaldehyde. During this time, it is estimated that about 150 tons of Hg were discharged to the bay. Following the outbreak of Minamata disease in 1956, in which humans became seriously ill after having ingested fish and shellfish contaminated with methylmercury, efforts were begun to 1) stop influx of mercury, and 2) remove the contaminated sediments. In 1965, the disease was also detected along the Agano River in Niigata Prefecture.

By 1974, the chemical plant had eliminated its discharges into the bay. By 1978, removal of contaminated sediment had been accomplished at 33 and 42 known sites across the country and the cleanup of Minamata Bay had begun. The north entrance to the bay was closed with concrete caissons and sheet pile to create a spoil area of 580,000 m^2 for the deposition of contaminated sediment. The most contaminated ($\geq$ 25 mg Hg/l of sludge) sediment will be pumped into this area. Trial dredging resulted in no increased fish tissue mercury concentrations. It is assumed that the Hg is probably in the form of mercuric sulfides which are strongly adsorbed to the fine sediment. Care will be taken to prevent the inorganic mercury from being methlyated by limiting available oxygen and sunlight to the dredged material. After dewatering, the dumpsite will be covered with uncontaminated soil and temporary breakwaters in the bay will be removed.

KEY WORDS: MERCURY, MINAMATA DISEASE, REVIEW, JAPAN

Ito, K. 1981.

ON HIGHLY CONCENTRATED ZINC CONTAINED IN THE LIVING BODY OF THE BARNACLE
(Abstract only. Transl. from Japanese.)
Pages 91-96 _in_ Nagoya City Environmental Pollution Research Report. No. 11.

The author collected barnacles clinging to the concrete walls and other things at 15 locations in the water of Nagoya Port and measured zinc concentrations of each barnacle. He carried out the examinations three times and studied the correlation between the zinc concentration in living barnacles and the zinc concentration in the water and mud. With regard to the mud, r=0.44. For the water, r=0.22-0.51. The large range in zinc concentrations in the latter was probably due to the rise and fall of the tide. When the difference between the rise and fall of the tide was small, r=0.3-0.5 was observed for zinc correlations between water and barnacles. No correlation was found when the difference in the rise and fall of the tide was large. Zinc was concentrated in the intestinal tracts of the barnacles.

KEY WORDS: ZINC, BARNACLES, JAPAN, CRUSTACEAN

Ito, K., S. Kajiyama, and M. Shimura. 1981.

A STUDY OF HEAVY METAL POLLUTION IN RIVERS, USING AQUATIC LIFE AS INDICATORS. I. (Abstract only. Transl. from Japanese.)
Pages 156-168 *in* Tokyo Metropolitan Environmental Pollution Institute Annual Report, Vol. 1981.

The content of mercury and its changes in the mud of the river bed were regularly studied from 1978 to 1980 in order to know the effect of turbidity in the Tamagawa water system. The same things were studied in insects and fish in the water. Insects and fish in the water had characteristics of stable mercury concentrations in the body, fixed living areas, and long life cycles. Due to these characteristics, the sampling was very easy. The study group sought some items which could be indicators of mercury pollution. They were not able to reach any conclusion because of lack of data.

KEY WORDS: MERCURY, FISH, INSECTS, JAPAN

Jacobs, R.P.W.M. 1980.

EFFECTS OF THE *AMOCO CADIZ* OIL SPILL ON THE SEAGRASS COMMUNITY AT ROSCOFF WITH SPECIAL REFERENCE TO THE BENTHIC INFAUNA.
Mar. Ecol. Prog. Ser. 2:207-212.

A spill of crude oil and Bunker C occurred at Roscoff, France. Direct effects of oil on eelgrass (*Zostera marina*) were only local and temporary, lasting only the first weeks of the spill. Many plants were found to have black 'burnt' leaves; however, production of new leaf tissue continued normally. Benthos was sampled using a 1-mm mesh sieve. Filter feeders were affected most because of a heavy rhizome mat and because grassblades lay over the bottom when oil was in contact with it. A sharp decrease in numbers of both individuals and species occurred (an almost total disappearance of Crustacea and Echinodermata). An exceptional growth rate in animals 1 month after a large mortality (3 months after the spill) was called a sign of imbalance in the ecosystem and was attributed to:

1. A stimulating effect of small amounts of some oil component
2. Increase in nutrients released from oil-killed organisms
3. Reduced population size of herbivorous gastropods which opened some niches
4. Normal increase of water temperature and irradiance after winter

Recovery took place relatively rapidly with all numbers except filter feeding Amphipoda returning to prespill levels in 1 year. In the Polychaeta, capitellids recovered quickly, followed by spionids, while the families Maldanidae, Terebellidae and Sabellidae were not fully recovered after 1 year.

KEY WORDS: OILS, GRASS, BENTHOS, FRANCE

Jernelov, A., and H. Lann. 1971.

MERCURY ACCUMULATION IN FOOD CHAINS.
Oikos 22:403-406.

The authors presented data from their research in lakes and rivers in Sweden which indicate the movement of mercury in the food chain. Inorganic mercury is metabolized rapidly in fish (pike in the examples cited), particularly in the liver. Though there is accumulation in the liver, the excretion rate is high. Therefore, there was very little or no accumulation in muscle or other tissues. On the contrary, methylmercury (which is generally just a small percentage of the total mercury) and other stable organics are not rapidly metabolized. These accumulate not only in liver, but also in kidney, brain and muscle tissues. An estimate, therefore, of the ratio of methylmercury in liver to that in muscle is useful, since the liver responds much more rapidly to environmental changes.

The authors contend that mercury accumulation through a food chain causes a basic concentration in the predator which is the same as their prey. To that basic level they accumulate more Hg directly from the water. For example, food chain accumulation by top fish predators (e.g., pike) was about 60% of the total in their tissue, while in bottom feeders, this figure was only 25%.

KEY WORDS: MERCURY, BIOMAGNIFICATION, BIOACCUMULATION, SWEDEN

Jones, A., and D. Ellis. 1976.

SUB-OBLITERATIVE EFFECTS OF MINE-TAILING ON MARINE INFAUNAL BENTHOS.
Water, Air Soil Pollut. 5:299-307.

The population density, biomass and length of *Ammotrypane aulogaster*, a sedentary polychaete of cosmopolitan distribution, was related to the amount of mine tailings in Rupert and Hoberg inlets, British Columbia, Canada. Replicate random samples were taken with a Van Veen grab in the fall at four stations, increasing in distance from a mine outfall. The stations nearer to the outfall showed significantly lower population density and biomass of the worms, which correlated with high values of deposited tailings. Since only a fall sample was taken, results are not conclusive, however. The authors note that more detailed time series sampling and analyses would have been more conclusive. Although a graph of tailing thickness at various locations is presented, the paper does not describe the kind of tailings involved, nor does it indicate any sediment concentrations of these tailings.

KEY WORDS: POLYCHAETE, MINE-TAILINGS, CANADA, BENTHOS

Klemmer, H.W. 1976.

MERCURY CONTENT OF BIOTA IN COASTAL WATERS IN HAWAII.
Bull. Environ. Contam. Toxicol. 15(4):454-457.

Mercury in benthic organisms was investigated in Hawaii. A total of 233 benthic organisms of 58 species were collected and anlyzed from four areas off the coast: two sites near Kilauea and McBryde sugar plantations along the northeast and south shores of Kauai; one site in Kahaua Bay along northeast Oahu; and one site in Mannalua Bay along southeast Oahu. The study showed significant differences in levels of Hg between trophic levels (one-way ANOVA; p=.001). The highest concentrations of Hg were found in those species which feed just above the sediment-water interface. There were no significant differences in Hg content within trophic levels (the other level being those

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animals feeding in direct contact with the sediment) or among the four areas sampled. Therefore, the author ruled out urban runoff or agricultural drainage effects. Rather, he surmised that the sediment itself is responsible for the levels of mercury in the organisms. No sediment values were given in the paper, however. Carnivores had the highest mean Hg values in both trophic groups, with 0.80 ppm in the sediment-water interface group, and 0.075 ppm in the direct sediment group.

KEY WORDS: MERCURY, BENTHOS, HAWAII

Kobylinski, G.J., and R.J. Livingston. 1975.

MOVEMENT OF MIREX FROM SEDIMENT AND UPTAKE BY THE HOGCHOKER, *TRINECTES MACULATUS*.
Bull. Environ. Contam. Toxicol. 14(6):692-698.

To determine the uptake of mirex from sediment and water by the bottom-dwelling flatfish *Trinectes maculatus*, the authors set up experimental aquaria in the laboratory. Both flow-through and static set-ups were employed. Sediment (coarse silica sand) concentrations were about 5,000, 1,650, and 500 ppb. Juvenile hogchokers were used in the experiments, and over the 4 week test period weekly assays were made for sediment and water concentration as well as fish muscle and liver tissue.

Only small quantities of mirex had leached from the sediment in the static tests, whereas the flow-through tanks leached fairly rapidly. By the end of the fourth week, 40-45% of the mirex had leached from the sediment in the flow-through sets. Bioaccumulation of the mirex by the fish was 3,800X in the static tests and 10,400X in the flow-through tests. This suggested to the authors that absorption from the water column alone would not accurately describe the accumulation of mirex observed. Also, since considerably more mirex was gained by the fish than was lost by the water, the fish probably absorbed significant amounts of mirex from the sediment. However, they did not discuss accidental ingestion of sediment by feeding or resting fish.

KEY WORDS: MIREX, FISH

Kosta, L., V. Ravnik, A.R. Byrne, J. Stirn, M. Deremilj, and P. Stegnar. 1978.

SOME TRACE ELEMENTS IN THE WATERS, MARINE ORGANISMS AND SEDIMENTS OF THE ADRIATIC BY NEUTRON ACTIVATION ANALYSIS.
J. Radioanal. Chem. 44:317-332.

This study, which took place in the northern Adriatic Sea, looked at As, Cd, Cu, Hg, Mn, Se and Zn levels in invertebrates, plankton, water and sediment. Mussels near a mining region contained up to 50 ppm of Hg in their tissues. In other regions, though, metals were at no higher levels than in other seas. Sharks were found to have up to 3.5 ppm Hg and Se in their tissues due to biomagnification. Mercury levels in a female ray were much higher than in her offspring. This is probably because in higher mammals, metals can cross the placental barrier. Mercury levels in the water column decreased with depth, possibly because the shallower water has more of the particular and organic matter to which Hg is absorbed. The plankton and sediment metal levels were within the normal range.

KEY WORDS: METALS, INVERTEBRATES, ADRIATIC SEA, PLANKTON

Koyanagi, T., M. Nakahara, and M. Iimura. 1978.

ABSORPTION OF SEDIMENT-BOUND RADIONUCLIDES THROUGH THE DIGESTIVE TRACT OF MARINE DEMERSAL FISHES.

J. Radiat. Res. 19:295-305.

The purpose of this study was to tract the pathways of radionuclides from sediment through the digestive tract of the demersal marine teleost *Kareius bicoloratus* in the laboratory. The premise was that in the field these fish have the potential to ingest sediment when they are feeding on worms and other bottom material. To this end, tracers (manganese-54, cobalt-60, and zinc-65) were added to seawater and graded sediment as chlorides and then shaken together for 1 week or 2 weeks. The radioactive sediment was then orally administered via gelatin capsules to the fish. Four fish were used for each radionuclide. After a week, the fish were sacrificed and the radioactivity of the various tissues and organs was determined.

Leachability of the radionuclides from sediment to water column was monitored at various pH levels in control set-ups. It was found that leachability increased as the pH decreased. For example, not much leached at a pH of 8.3. This latter point is important when one considers that after initial ingestion of the capsule (or food in the natural environment), the fish stomach becomes strongly acidic. As a result of the ingestion of radioactive sediment, high levels of radioactivity in the intestine and even higher levels in the liver and kidney suggested that there is a rapid transfer to these organs. Indeed, within 24-48 hours, 70% of the zinc-65 was lost from the body, 80% of the manganese-54 and cobalt-60 were lost and 97% of the iron-59 was lost. Muscle tissue showed the lowest concentrations in all experiments, which indicated to the authors that the potential for harm to man is not great, since muscle tissue would usually be the portion ingested by humans. No other fishes were tested in this regard, however.

KEY WORDS: RADIONUCLIDES, FISH, METALS

Krebs, C.T., and K.A. Burns. 1977.

LONG-TERM EFFECTS OF AN OIL SPILL ON POPULATIONS OF THE SALT-MARSH CRAB, *UCA PUGNAX*.

Science 197:484-487.

In a long-term study of the 1969 oil spill at West Falmouth, Massachusetts the authors monitored density, larval recruitment and settling, mortality, behavior and other aspects of the fiddler crab, *Uca pugnax*. Sediment surface concentrations of oil which contained greater than 20% aromatics were directly toxic to adults. Concentrations of 100-200 ppm total oil were toxic to overwintering juveniles. Where concentrations were less than 100 ppm, repopulation was almost complete. Finally, those stations which were most heavily oiled (e.g., up to 6,000 ppm initially) still exhibited adverse reactions (juvenile abnormalities, lower crab populations than less-oiled or non-oiled stations) more than 7 years after the spill.

KEY WORDS: OILS, CRUSTACEAN, MASSACHUSETTS, CRAB

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Krebs, C.T., and I. Valiela. 1978.

EFFECT OF EXPERIMENTALLY APPLIED CHLORINATED HYDROCARBONS ON THE BIOMASS OF THE FIDDLER CRAB, *UCA PUGNAX* (Smith).
Estuarine Coastal Mar. Sci. 6:375-386.

Fertilizer made from sewage sludge was used to contaminate experimental salt marsh plots. Although the sludge also contained heavy metals and probably some industrial wastes besides aldrin and dieldrin, the hydrocarbon fraction was the only part that showed toxicity. No evidence of avoidance of fertilized areas by the crabs was observed; thus, all population decreases were due to mortality. The density of crabs was reduced to 47±5 crabs/m^2 at a lower dose of fertilizer and to 16±1 crabs/m^2 with a higher dose, compared to 113±10 crabs/m^2 in control plots. Younger crabs were affected more than older crabs. Decreases in populations were due to both mortality from treated areas and increased predation due to slowed escape responses. The annual loss to immigrant mortality amounted to 20 g dry weight/m^2 in the low dose plots and 99 g/m^2 in the high dose plots. It was hypothesized that the lack of effects of hydrocarbons on crabs observed in other experiments was due to continual recolonization by new crabs. The mean standing crop of fiddler crabs in untreated areas was 29 g dry wt/m^2, which was higher than the biomass of most other salt marsh invertebrates.

KEY WORDS: MARSH, CRAB, SEWAGE SLUDGE, MASSACHUSETTS, CRUSTACEAN

Langston, W.J. 1978.

ACCUMULATION OF POLYCHLORINATED BIPHENYLS IN THE COCKLE *CERASTODERMA EDULE* AND THE TELLIN *MACOMA BALTHICA*.
Mar. Biol. 45:265-272.

Two species of marine clam, *Cerastoderma edule* (a cockle), and *Macoma balthica* (a tellin), were subjected to artificial sediment (particles of alumina) which had been contaminated with three PCB's: Aroclors 1242, 1254, and 1260. At intervals up to 40 days, specimens were removed and their tissues were analyzed. Maximum tissue concentrations ranged from 70-240X the ambient concentration. The author indicated that the data are insufficient to determine whether the maximum concentrations of Aroclors 1242 and 1254 were reached. However, Arclor 1260 reached 17 ppm at 20 days with no significant increase thereafter. The author concluded that ingestion of contaminated particles is an important means of entry into bivalve tissues.

KEY WORDS: PCB, MOLLUSKS, CLAM

Laube, V., S. Ramamoorhty, and D.J. Kushner. 1979.

MOBILIZATION AND ACCUMULATION OF SEDIMENT BOUND HEAVY METALS BY ALGAE.
Bull. Environ. Contam. Toxicol. 21:763-770.

Surface area, organic content, and cation exchange properties of sediments are factors affecting metal sorbtion to sediments. Sediments with high levels of sulfides and organic nitrogenous compounds are best at adsorbing copper and cadmium. In this lab study, the algae (*Anabaena* and *Ankistrodesmus*)

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showed considerable uptake of metals when the only source was the sediment, even though the water was acting as the medium of metal transport and showed only negligible metal levels. In 72 hours, 7-20 ppm Cu and 9-20 ppm Cd were accumulated in the algae. Accumulation of metals from the sediment by algae could make metals available to higher trophic levels.
KEY WORDS: METALS, BIOACCUMULATION, ALGAE

Lee, C.R., T.C. Sturgis, and M.L. Landin. 1976.

A HYDROPONIC STUDY OF HEAVY METAL UPTAKE BY SELECTED MARSH PLANT SPECIES.
Tech. Rep. D-76-5. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 47 pp. + Append.

Six marsh plants were grown hydroponically in the laboratory to determine the uptake of metals from chemically fixed solutions containing heavy metals. The metals, each at concentrations of 0.0, 0.5 and 1.0 ppm, were: Cd, Cr, Ni, Pb, and Zn. The authors found that *Cyperus esculentus*, *Distichlis spicata*, *Spartina alterniflora* and *S. patens* each have more potential than the other plants studied (*Scirpus robustus*, *Scirpus validus*, *Spartina foliosa* and *Triglochin maritima*) to take up Zn, Cd, and Ni. All of the plants, however, took up Cr and Pb, but there was little translocation of these metals from the roots to the leaves.
KEY WORDS: METALS, MARSH PLANTS, HYDROPONIC, BIOACCUMULATION

Lee, C.R., R.M. Smart, T.C. Sturgis, R.N. Gordon, and M.C. Landin. 1978.

PREDICTION OF HEAVY METAL UPTAKE BY MARSH PLANTS BASED ON CHEMICAL EXTRACTION OF HEAVY METALS FROM DREDGED MATERIAL.
Tech. Rep. D-78-6. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 55 pp. + Append.

This paper describes the extent of heavy metal uptake by several species of cordgrass (*Spartina alterniflora*, *S. patens* and *S. spicata*) at spoil disposal sites in Connecticut, New Jersey, Delaware, Maryland, North Carolina, Georgia, Florida, Alabama, Louisiana and Texas. Laboratory procedures for analyses appeared to be satisfactory except that 1) sampling sites within a marsh appeared to be best guesses (i.e., they did not analyze regions within a marsh to test for variations), and 2) leaves and roots were examined, but not stems. The latter may not be very important, but the former could be if, indeed, growth patterns vary within marshes. Metal analyses were for Zn, Cd, Cu, Pb, Cr, and Ni. The ultimate aim of the study was to develop "prediction equations" for metal uptake from known concentrations in the sediment.

The results were instructive when compared to literature values for natural (uncontaminated) marshes. For most metals, the uptake in contaminated areas was no greater than in uncontaminated marshes. In a few locations, however, *S. patens* and *S. alterniflora* exhibited an order of magnitude greater uptake of Pb over ambient. Correlations between soil extractable metals and plant content were significant in some cases and "prediction equations" were presented. However, the derivations of the equations are not developed fully in the text. The authors conclude that, while most marsh plants in the study had relatively low amounts of heavy metals, more research is needed to determine the potential hazards involved in metal uptake.
KEY WORDS: MARSH PLANTS, METALS, BIOACCUMULATION

Lee, R.F. 1977.

ACCUMULATION AND TURNOVER OF PETROLEUM HYDROCARBONS IN MARINE ORGANISMS.
Pages 60-70 in D.A. Wolfe, ed. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

This review paper deals with uptake, storage and discharge of petroleum hydrocarbons by marine organisms under lab and field conditions. Depuration rates for laboratory-exposed animals were usually greater than animals in the field exposed to oil spills or chronic pollution. Depuration rates also vary with type of animal, geography and oil type. For example, shrimp depurated #2 fuel oil in 2 days, while fiddler crabs were still affected 4 years later. Longer periods of exposure resulted in slower depuration rates and may allow hydrocarbons to be stored in the animal's stable tissues. Many crustaceans take up petroleum rapidly from food or water and store it in the hepatopancreas. From there, most is metabolized and eliminated through feces or urine. Some polychaetes, such as Capitella capitata, have enzymes that metabolize hydrocarbons. The differing uptake rates between bivalves may be due to different filtering rates and lipid contents. Bivalves are proposed to be used as bioaccumulation monitors.

KEY WORDS: REVIEW, PETROLEUM HYDROCARBONS, BIOACCUMULATION, OILS

Leland, H.V., S.N. Luoma, J.F. Elder, and D.J. Wilkes. 1978.

HEAVY METALS AND RELATED TRACE ELEMENTS.
J. Water Pollut. Control Fed. 50:1469-1514.

This paper is a literature review dealing with metal contamination in water, its effect on algae, water and fish, and its forms in the sediment. Many examples of metal effects on organisms, both lethal and sublethal, were given. For example, mercury uptake in a freshwater diatom was affected by the light-dark cycle, with more Hg being taken up in the light than in the dark. Some algae also showed this light-related uptake rate with Fe, but not with Cu. Low pH was found to increase Cd and Ca uptake in some plants. High calcium levels slowed the rate of copper equilibration in an organism's tissues.

Macroalgae and benthic bivalves were usually found to be the best indicator species. Seasonal variations in metal concentrations have been recorded. There was no constancy in any metals concentration-effect curve among all species. The physicochemical form of the metal may be as important in metal concentration as anything else and is not related to the stability of the complex. This is also true for some radionuclides (Americium-241). Accumulation of Pb, Zn, Cu and Cd through a food chain was strongly influenced by the cation-exchange capacity of the sediment.

KEY WORDS: METALS, REVIEW

Leppakoski, E.J., and L.S. Lindstrom. 1978.

RECOVERY OF BENTHIC MACROFAUNA FROM CHRONIC POLLUTION IN THE SEA AREA OFF A REFINERY PLANT, SOUTHWEST FINLAND.
J. Fish. Res. Board Can. 35:766-775.

Quantitative field studies on benthic sublittoral macrofauna were made in the vicinity of an oil refinery in southwest Finland before and after the installation of a new wastewater treatment plant. Rate of recovery of sublittoral bottoms to chronic pollution depends on rate and selective efficiency of oil biodegradation. Species diversity increased during the 1st and 2nd year after pollution abatement. The large increase in species the first year after pollution abatement may be temporary and artificial since 3 years after the plant started, deeper soft-bottomed sediments were azoic. After 4 years, improvement in the sediment became apparent and fauna resembled those of organically enriched sounds with four species (a clam, a polychaete, an insect larva, and an oligochaete) making up 95% of the individuals in the polluted area. The results demonstrate not only the recovery from chronic oil pollution but also the degree of ecological damage caused by previous continuous discharge of oil. It was also concluded that 4 years is not enough time to monitor complete recolonization of the area.

KEY WORDS: OILS, FINLAND, BENTHOS

Levings, C.D., and N.G. McDaniel. 1975.

INDUSTRIAL DISRUPTION OF INVERTEBRATE COMMUNITIES ON BEACHES IN HOWE SOUND, B.C.
Fish. Mar. Serv. Res. Dev. Tech. Rep. 663. 105 pp.

This study observed mostly the beach environments of Howe Sound, B.C., Canada. Inorganic solid wastes, such as discharge by gravel-washing plants, deposits of mine tailings, and a spill of "line-mud" tended to bury and smother much flora and fauna. It also clogged the filter-feeding apparatus of mussels and barnacles. Mine tailings also contained some heavy metals (e.g., Cu and Zn) which were found to have deleterious effects on the subtidal benthos. Draft mill effluents, which, along with Cu and Hg are the major Sound contaminants, significantly decreased oyster growth due to the oyster's shell closing in its presence. Copper levels in the water may affect amphipod distribution in Howe Sound.

KEY WORDS: BEACHES, INVERTEBRATES, MOLLUSKS, CRUSTACEAN, CANADA

Lyles, M.C. 1979.

BIOAVAILABILITY OF A HYDROCARBON FROM WATER AND SEDIMENT BY THE MARINE WORM, *ARENICOLA MARINA*.
Mar. Biol. 55(2):121-127.

C^{14}-1-naphthalene was placed in aquaria at a concentration of 30 μl/l in the water and sediments. Worms were then placed in the aquaria and allowed to take up the naphthalenes for several hours. The worms were dissected and a

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liquid scintillation counter was used to count the amount of naphthalene in the worms' systems. It was found that the worms take up naphthalene from the water rather than the sediments. The stomach wall and esophagael glands are the most important uptake sites. Worms probably are not very effective at cleaning sediments. Even so, worm processing makes hydrocarbons more liable to degradation and so speeds up sediment cleanup.

KEY WORDS: HYDROCARBONS, POLYCHAETE, NAPHTHALENE

McCain, B.B., H.O. Hodgins, W.D. Gronlund, J.W. Hawkes, D.W. Brown, M.S. Myers, and J.H. Vandermeulen. 1978.

BIOAVAILABILITY OF CRUDE OIL FROM EXPERIMENTALLY OILED SEDIMENTS TO ENGLISH SOLE (*PAROPHRYS VETULUS*), AND PATHOLOGICAL CONSEQUENCES.
J. Fish. Res. Board Can. 35:657-664.

English sole were exposed to experimentally oiled sediments over a 4-month period. Initially, crude oil was mixed with aromatic hydrocarbon-free sediments to a concentration of 700 µg/g dry weight. During the first month, this concentration decreased to 400 µg/g and remained relatively stable during the remainder of the 4-month period. A steep hydrocarbon concentration gradient appeared between the top 1 cm (43 µg/g dry wt) and the bottom 4 cm of sediment (540 µg/g). Changes were also observed in the alkane and aromatic fractions.

Flatfish readily took up alkane and aromatic petroleum hydrocarbons from these sediments, and accumulated these in skin, muscle, and liver. The oil-exposed sole appeared less active and did not feed as well as the control fish. Tissue hydrocarbons decreased with time. After 27 days continuous exposure, only the liver contained detectable levels of hydrocarbons. After 2 months, <2% of the initial aromatic hydrocarbon load could be detected, and only in the liver; 1, 2, 3, 4-tetramethylbenzene and 2-methylnaphthalene were the most persistent entities. Depuration in the fish is thought to be due to induction of the aryl hydrocarbon hydroxylase system during initial exposure to oiled sediments. Associated with the high tissue hydrocarbon period were enhanced weight loss and severe hepatocellular lipid vacuolization. Hemoglobin levels were higher in oil-exposed fish for the first 50 days and then returned to regular levels, possibly due to the decrease of hydrocarbon levels in the sediment.

KEY WORDS: OILS, FISH, BIOAVAILABILITY

McGreer, E.R. 1979.

SUBLETHAL EFFECTS OF HEAVY METAL CONTAMINATED SEDIMENTS ON THE BIVALVE *MACOMA BALTHICA* (L.).
Mar. Pollut. Bull. 10:259-262.

Sublethal effects of estuarine sediments containing high levels of heavy metals were studied using the marine bivalve, *Macoma balthica*. Burrowing behavior was inhibited in all contaminated sediments compared to the control. A comparison of concentrations of individual metals vs. burrowing response times showed that mercury and cadmium significantly altered burrowing rates.

An active threshold avoidance response by *M. balthica* to the sediment containing the highest metal levels was also demonstrated.
KEY WORDS: METALS, CLAM, CANADA, SHELLFISH

McGreer, E.R., B.J. Reid, and H. Nelson. 1980.

MOBILIZATION, BIOACCUMULATION, AND SUBLETHAL EFFECTS OF CONTAMINANTS FROM MARINE SEDIMENTS.
Pages 130-151 *in* N. Bermingham, C. Blaise, P. Couture, B. Hummel, G. Joubert, and M. Speyer, eds. Proc. 7th Annual Aquatic Toxicity Workshop: Nov. 5-7, 1980. Montreal, Quebec. Can. Tech. Rep. Fish. Aquat. Sci. No. 990.

Laboratory studies were conducted to determine the mobilization and bioaccumulation of contaminants (Cd, Cu, Pb, Zn, As, Hg and PCB's) from marine sediments by the deposit-feeding clam, *Macoma balthica*, and the filter-feeding mussel, *Mytilus edulis*. Some Cu, Pb, Zn and As desorbed from the sediments and went into the water within 30 days. Cd, Pb, Hg and As were bioaccumulated from the sediment during the 30-day test. The filter feeder took up Cd, Pb, Zn and Hg in the greatest quantities, while the deposit feeder took up more As and PCB's. Metals in control sediments were bioaccumulated more than metals in contaminated sediments. This lack of accumulation may be due to organic chelating agents present in the sediments. Cd was found to most affect burrowing behavior.
KEY WORDS: METALS, BIOACCUMULATION, CLAM, SHELLFISH

Michael, A.D. 1977.

THE EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE POPULATION AND COMMUNITIES.
Pages 129-137 *in* D.A. Wolfe, ed. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

Topics covered in this review paper included the effects of oil on plankton, benthos, birds and mammals, spills vs. chronic pollution and ecological effects. The author advocates looking at the long-term, low level effects of areas to monitor long term decay.

The physical effects of oil on benthos include smothering, abrasion, removal and alteration of substrates. Two ways that animals have to minimize these effects are by projecting out of the oil or by possessing a mucus covering. Light fuel oil is very toxic, whereas heavier crude oil is not so dangerous. Oil stranded on shore is broken down by physical means--the more extreme, the faster the breakdown; hence, hydrocarbon content is much higher in mud than sandy areas equally exposed initially. Subtidal areas are subjected to long-term effects of exposure. *Mya arenaria* in Maine were dying from a fuel oil spill 3 years after it occurred.

Animals can survive a one-time oiling better than they can chronic pollution. Even so, the sublethal effects of oil may decrease tolerance to physical extremes or reduce competitiveness in the community. The polychaete, *Capitella capitata*, responds so well to oiled areas not only because of its high individual tolerance, but also because of its greater genetic flexibility. Oil is a much greater problem in cold environments because:

1. Aromatics do not evaporate as quickly.
2. The rate of bacterial degradation and weathering is slower.
3. Cold species are longer-lived with low reproductivity and small dispersal ranges so they cannot recover as quickly.

KEY WORDS: REVIEW, HYDROCARBONS, BENTHOS

Miramaud, P., P. Germain, and H. Camus. 1982.

UPTAKE OF AMERICIUM AND PLUTONIUM FROM CONTAMINATED SEDIMENTS BY THREE BENTHIC SPECIES: ARENICOLA MARINA, COROPHIUM VOLUTATOR AND SCROBICULARIA PLANA.
Mar. Ecol. Prog. Ser. 7:59-65.

The purpose of the experiments described in this paper was twofold: 1) to quantify the transfer of radioactive americium-241 and plutonium-238 from sediment to selected organisms, and 2) to quantify the transfer of those elements from seawater to those organisms. Infauna of three different classes were chosen to verify and extend earlier work by others on the uptake of americium-241 and plutonium-238. Instead of the commonly used clam worm, Nereis, they chose to work with another polychaete, Arenicola marina, an amphipod, Corophium volutator, and a bivalve mollusk, Scrobicularia plana. The animals were placed in labeled sediment and left for 14 days under flow-through conditions using clean seawater. Transfer factors were calculated at the end of the 2 weeks. These factors were all low, less than one, and C. volutator absorbed the radionuclides better than S. plana, which in turn absorbed better than A. marina.

In transfer experiments using labeled seawater, however, the transfer factors were higher, especially in C. volutator. Also in the water uptake experiments, all three species preferentially took up Am over Pu. Though the uptake of radioactive substances from the sediment was small, it did confirm what had already been known from Nereis experiments, namely that the radioactive material is available, although not easily available, to benthic organisms. As a check on artifacts, the authors analyzed tissues, but found no sediment particles in guts. Therefore, they assumed that the transfer of the radionuclides took place in the experiments.

KEY WORDS: RADIONUCLIDES, AMERICIUM, PLUTONIUM, AMPHIPOD, MOLLUSKS, POLYCHAETE, CRUSTACEAN, OILS

Montgomery, J.R., and M.T. Price. 1979.

RELEASE OF TRACE METALS BY SEWAGE SLUDGE AND THE SUBSEQUENT UPTAKE BY MEMBERS OF A TURTLEGRASS-MANGROVE ECOSYSTEM.
Environ. Sci. Technol. 13:546-549.

A model ecosystem, in operation at Mayaguez, Puerto Rico, is the subject of this report on metal uptake (Cd, Cr, Cu, Ni, Pb, and Zn) by the turtlegrass, mangroves and animals which make up that system. The experiments lasted 125 days. Though fouling organisms took up much of the leached metals from sludge which was placed on top of calcareous-sand substrate, the leaves of Thalassia testudinum (turtlegrass) did show a net uptake of Cr, Ni, Pb and Zn. Sea urchins and sea cucumbers also demonstrated uptake of those metals,

as did the roots of the red mangrove, *Rhizophora mangle*. The authors concluded that it is unwise to place sewage sludge on a seagrass-mangrove based system because of the probability of leached metals being taken up by community members.
KEY WORDS: METALS, MANGROVES, SEAGRASS, SEWAGE SLUDGE, PUERTO RICO

Moore, J.W., V.A. Beaubien, and D.J. Sutherland. 1979.

COMPARATIVE EFFECTS OF SEDIMENT AND WATER CONTAMINATION ON BENTHIC INVERTEBRATES IN FOUR LAKES.
Bull. Environ. Contam. Toxicol. 23:840-847.

In this investigation, the concentrations of heavy metals in the sediments and waters of four lakes situated in the Canadian subarctic were determined from May 1977 to May 1978, and were correlated with differences in the species composition, diversity and density of the benthic communities. There was a gradient of increasing faunal diversity proceeding downstream from a gold mine. Insects and mollusks were the only animals close to the mine. Downstream, more species appeared and amphipods became more important as downstream distance increased. The authors determined from the data that the concept of indicator species is not very valuable in general and there are not enough species in the north to be worthwhile in specific cases.
KEY WORDS: ARCTIC, BENTHOS, CANADA, METALS

Moore, J.W., and D.J. Sutherland. 1980.

MERCURY CONCENTRATIONS IN FISH INHABITING TWO POLLUTED LAKES IN NORTHERN CANADA.
Water Res. 14:903-907.

The concentrations of total mercury in the sediments, water and fish of Giauque Lake and Thompson Lake in northern Canada were determined during 1977 and 1978. Both lakes had formerly received mercury-ladden industrial discharges, which were terminated in 1968 (Giauque Lake) and 1949 (Thompson Lake). Lake trout (*Salvelinus namaycush*) contained an average of 3.79 mg/kg in muscle while concentrations in northern pike (*Esox lucius*) and round whitefish (*Prosopium cylindraceum*) were 1.75 and 1.22 mg/kg, respectively. About 7% of the lake bottom contained mercury levels greater than 500 μg/kg dry weight. In Thompson Lake, mercury levels in northern pike averaged 1.69 mg/kg, whereas in lake whitefish (*Coregonus clupeaformis*), the highest recorded value was 0.6 mg/kg. Approximately 15% of the lake bottom contained mercury in excess of 500 μg/kg, with values reaching 1,300 μg/kg. Mercury levels in the water column in both lakes were usually below detectable limits (0.2 μg/l).

Since even young pike had elevated levels of Hg in their muscle tissue, the authors concluded that Hg had been rather recently assimilated into the flesh. Therefore, they concluded that pike are still accumulating mercury from exposed tailings which were deposited in Thompson Lake 30 years ago. Further, contamination of one part of the lake can result in high levels in fish throughout the lake because of the motility of the animals. The authors did not study the dynamics of mercury in the lakes, but surmised that processes such as methylation are continuing at the dump sites.
KEY WORDS: MERCURY, FISH, ARCTIC, CANADA

Murakami, G., Y. Nouma, M. Kida, and K. Aomori. 1980.

AN OBSERVATION ON THE DUMPING OF THE OIL SLUDGE INTO THE SEA. (Abstract only. Transl. from Japanese.)
Natl. Environ. Pollut. Res. Mag. 5(2):90-92.

The authors utilized the examination methods for oil which was dumped into the sea (notification regulation of the Environmental Agency) and the oil content test, using the sludge obtained at a gas station as reference material. The notification regulation of the Environmental Agency and the standard for judgment were discussed. The results were the following: 1) the standard for judgment was too high because that standard was 10,000 times higher than the oil concentrations in the water which imparted a bad smell to fish, and 2) the effects of oil in the substrate were greater than the effects of oil in the water which imparted a bad smell to fish. Therefore, it was necessary to switch from the current liquation test to the content test.
KEY WORDS: OILS, FISH, JAPAN

Murphy, C.B., Jr. 1981.

BIOACCUMULATION AND TOXICITY OF HEAVY METALS AND RELATED TRACE ELEMENTS.
J. Water Pollut. Control Fed. 53(6):993-999.

This is a review paper of recent reports and papers on all metals which are placed in the heavy metal category. The review cites documents which deal with heavy metal distribution in the environment, bioaccumulation, general toxicity literature, detoxification and applications of heavy metal toxicity.
KEY WORDS: REVIEW, BIOACCUMULATION, HEAVY METALS

Murphy, T.A. 1971.

ENVIRONMENTAL EFFECTS OF OIL POLLUTION.
J. Sanit. Eng. Div. Proc. Am. Soc. Civ. Eng. 97:361-371.

The West Falmouth spill was the first time modern methods of chemical analysis and biological observation were used to document an oil spill. There was a massive initial mortality of all types of exposed biota. As the oil dissipated, the area of bottom affected increased. No repopulation was observed 9 months after the spill. Mollusks in the area readily took up oil. No depuration of oil from the tissues was observed 6 months after the spill. Marsh plants were killed, so properties of the sediment were changed making erosion possible. Chronic oiling, not the single spill, should be the main source of concern about oil pollution.
KEY WORDS: OILS, MASSACHUSETTS

Murray, C.N., and A. Avogadro. 1979.

EFFECT OF LONG-TERM RELEASE OF PLUTONIUM AND AMERICIUM INTO AN ESTUARINE-COASTAL SEA ECOSYSTEM. I. DEVELOPMENT OF AN ASSESSMENT METHODOLOGY.
Health Phys. 36:573-585.

A method was developed for the assessment of the distribution and the associated hazard due to a long-term release of long-lived alpha-emitting radionuclides into surface waters of a marine ecosystem. The compartment model system chosen for use here is applied to an imaginary coastal sea.

Concentration levels for the conditions used in the present work produce rather low dose rates to man of less than 3% of the maximum permissible intake. Low dose levels depend upon the concentration factors of the various biological activities, as well as upon source-term activities. Where highly radioactive sediments were closely involved in the uptake pathway, actinide transport to man could become more relevant.

Sedimentation and bottom sediment absorption represent the major reconcentration process for actinides released into surface waters. There is a need to continue radiological research on the benthic zone to understand the significance of the long-term sediment-biota interactions.

KEY WORDS: RADIONUCLIDES, MODELLING, BIOMAGNIFICATION, PLUTONIUM, AMERICIUM, METALS

Murray, C.N., and A. Avogadro. 1981.

EFFECT OF A LONG-TERM RELEASE OF PLUTONIUM AND AMERICIUM INTO AN ESTUARINE AND COASTAL SEA ECOSYSTEM.
Pages 103-114 _in_ Techniques for Identifying Transuranic Speciation in Aquatic Environments. International Atomic Energy Agency Panel Proceedings Series. Vienna.

Plutonium occurs primarily in two ionic states--(IV) and (VI). The (IV) state is much more abundant and parallels sediment activity, while the (VI) state is the more mobile form. Average plutonium ion ratios in river water are 99.7% : 0.3% (IV : VI), while in estuaries the ratio is 90% : 10% (IV : VI). Americium is much less mobile than plutonium. Americium-241 produced by plutonium-241 decay has a more widespread effect than americium-241 which is simply dumped into the water. The biokinetics of these different forms are very complex and not well understood. However, the authors point out that _in situ_ production of water-soluble forms may be a long-term source of mobile species in the environment. Further, the effect of different sources of input on the bioavailability must be considered when predicting long-term effects.

KEY WORDS: RADIONUCLIDES, PLUTONIUM, AMERICIUM, METALS

Nakanishi, H. 1981.

SHIFT OF PCB IN THE WATER PLANTS AND SHELLFISH IN THE SOUTH PORTION OF LAKE BIWA. (Abstract only. Transl. from Japanese.)
Ecol. Chem. 4(3):23-29.

PCB's released into the environment flowed into Lake Biwa due to the geographical characteristics of Shiga Prefecture. It was ingested by the fish, shellfish, water plants, and wild birds which inhabited the lake. A small mud snail[1] was chosen as a subject for analysis. The small Canadian alga[1] and the large Canadian alga[1] were chosen as the subjects for analysis among the water plants. The methods of analysis and the results are presented in the report.

KEY WORDS: MOLLUSKS, PLANTS, PCB, JAPAN

Nakanishi, H., and M. Ukita. 1977.

STUDIES ON PCB POLLUTION OF FISHES, SHELLFISHES, AND BOTTOM MUD IN THE BAY OF TOKUSHIMA. (Abstract only. Transl. from Japanese.)
Pages 163-168 *in* Collection of Lectures, Hygienic Engineering Research Discussion, Vol. 13.

Two soda factories are the primary sources of mercury in the Bay of Tokuyama. They have consumed 508 tons of mercury and have dumped 9.4 tons of mercury into the natural environment since beginning production of caustic soda via mercury electrolysis in 1952. It is estimated that the actual amount of mercury dumped may approach 36.3 tons, based on the analysis of the surface level of the sea bottom in the bay. The mercury is concentrated in the surface layer of 20 cm depth. This layer is added to by 1 cm per year. The bottom mud contains mercury in concentrations of 11-22 ppm. From 50-90% of the mercury is in the form of sulfide, and the rest is ionic mercury and metal mercury. Alkyl mercury has not been detected. The values of mercury in fishes and shellfishes have also been examined. The values of mercury in fishes and shellfishes are above the regulated values. Dredging work is underway in order to remove bottom mud which exceeds a total mercury content of 15 ppm.

KEY WORDS: PCB, MERCURY, FISH, SHELLFISH, JAPAN

Nathans, M.W., and T.J. Bechtel. 1977.

AVAILABILITY OF SEDIMENT-ADSORBED SELECTED PESTICIDES TO BENTHOS WITH PARTICULAR EMPHASIS ON DEPOSIT-FEEDING INFAUNA.
Tech. Rept. D-77-34. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 62 pp. + Append.

The authors present their work on the ability of benthic infauna to absorb pollutants from the sediment. The worms selected, *Nephthys californiensis*, *Capitella capitata*, and *Tubifex tubifex* were set up in aquaria containing natural and artificial sediments with radioactive DDT (carbon-14-labeled). The artificial sediments may or may not reflect uptake which might occur in natural substrate, according to the authors, but it was thought that by manipulating the composition of sediment, differences in uptake ability by a species would be readily apparent. The artificial sediments were silica sand-clay-pablum mixtures. Unfortunately, achieving the right mixtures to sustain the animals was a problem with the methodology. *Capitella capitata* did not survive well at all. *Nephthys* and *Tubifex* fared better as the amount of the cereal component was adjusted downward to 0.1-1.0% of the total sediment make-up (sand comprised about 99%).

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[1] No taxonomic names were listed in the abstract.

The limited results indicated that DDT was taken up by the animals from the clay and organic fractions of the sediment. In a brief bioaccumulation experiment, *Tubifex* accumulated DDT by a factor of 2 over the sediment. For *Nephthys* the factor was 8, and for *Capitella* the factor ranged from 50-70. The authors indicated that a great deal of additional research is needed.

KEY WORDS: BENTHOS, PESTICIDES, DDT, BIOACCUMULATION, POLYCHAETE

Neff, J.W., R.S. Foster, and J.F. Slowey. 1978.

AVAILABILITY OF SEDIMENT ABSORBED HEAVY METALS TO BENTHOS WITH PARTICULAR EMPHASIS ON DEPOSIT-FEEDING INFAUNA.
Tech. Rep. D-78-42. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 286 pp.

The first section of this report is a review of the accumulation of metals in biota followed by summarized generalizations based upon that literature. The second section describes a series of experiments in which benthic invertebrates were exposed to natural substrates of known metal concentration. These studies were to determine: 1) the accumulation and uptake of metals, 2) effect of salinity on heavy metal uptake, 3) depuration of metals after removal of the organisms from the substrate, and 4) correlations of tissue metal forms with sediment forms. Sediments were taken from the Texas City and Corpus Christi ship canals and Ashtabula (Ohio) Harbor. Animals used were *Rangia cuneata*, *Paleomonetes kadiakensis*, *Paleomonetes pugio*, *Neanthes arenaceodentata*, and *Tubifex* sp. For each sediment type, and at each of three salinities [0, 15, and 30 parts per thousand (ppt)], three reps were run of both control and experimental aquaria at 20±2°C. Each experimental aquarium contained set numbers of each species (e.g., 5 *R. cuneata*, 25 *P. kadiakensis*). Animals were removed for analysis at 2, 4, 8, 16, and 32 days. Another tank contained large numbers of the experimental organisms to determine long-term uptake from each of the sediments. The long term experiment lasted 9 months, and animals were removed every week during the first month and every 2 weeks thereafter.

Out of a total of 136 metal-organism-sediment combinations, 49 (36%) demonstrated significant correlations between exposure to sediment and heavy metal concentration in animal tissues. However, 13/49 were negative correlations. Therefore, a positive correlation was found in 26.5% of the cases. For certain metals, such as Fe, the correlation was 50%. Others, such as Pb, were less (30% in the case of *N. arenaceodentata*, for example), but the significance of the latter may be greater than for Fe because of the greater *arenaceodentata* occurred only once. Similarly, significant Hg concentration was recorded only once in *R. cuneata*. Inter-species differences depended on pH and Eh of the gut, permeability of the integument, nutritional status of the animal, etc. However, one overriding factor appeared to be salinity. *Rangia*, for example, consistently accumulated lower concentrations of metals at lower salinities. In the long-term experiment, there was only one case of significant accumulation at 15 ppt and 30 ppt, whereas this occurred 12 times at lower salinity. The authors concluded, therefore, that the salinity of the ambient medium is important to metal uptake. They also suggested doing bioassays if metal content of sediment to be spoiled is high. They did not, however, define what these levels might be.

KEY WORDS: METALS, BIOAVAILABILITY, BENTHOS, REVIEW

Nimmo, D.R., P. Wilson, R. Blackman, and A. Wilson, Jr. 1971.

POLYCHLORINATED BIPHENYL ABSORBED FROM SEDIMENTS BY FIDDLER CRABS AND PINK SHRIMP.
Nature 231:50-52.

Aroclor 1254 is a variety of PCB found in Escambia Bay, Florida. Penaeid shrimp caught there had levels of PCB's up to 14 ppm in their tissues, mostly in the hepatopancreas. Concentrations of Aroclor 1254 in sediment ranged between 0.6-61 ppm. Fiddler crabs had .45-1.5 ppm in their bodies.

Laboratory experiments on uptake were also done. The amount of PCB in an animal was usually related to the amount of PCB in sediments. Apparently animals either ate contaminated sediment particles, or absorbed PCB's through their cuticle.

KEY WORDS: PCB, CRUSTACEAN, FLORIDA

Odum, W.E., G.M. Woodwell, and C.F. Wurster. 1969.

DDT RESIDUES ABSORBED FROM ORGANIC DETRITUS BY FIDDLER CRABS.
Science 164:576-577.

DDT and its metabolites accumulate in organic plant detritus and may persist there for many years. Residues appear to be most abundantly associated with particulates having diameters from 250-1,000 microns. Detritus particles of this size are ingested by many organisms and the pesticide residues are concentrated in the lipids of scavengers and carnivores.

Fiddler crabs (*Uca pugnax*) were fed detritus containing 10 ppm DDT residues. By day 4 of this 11-day experiment, some crabs showed grossly modified behavior and were having coordination problems. This was associated with a threefold increase in concentration of DDT in the muscle of the large claw. This poor coordination makes the crabs more susceptible to predation and may explain why some populations of crabs around areas of high DDT concentration have been eliminated.

KEY WORDS: DDT, CRABS, CRUSTACEAN, PESTICIDES

Okano, S., R. Koike, and K. Taguchi. 1979.

A STUDY CONCERNING THE WATER TURBIDITY OF KASUMIGAURA LAKE. DISTRIBUTION OF RADIONUCLIDES. (Abstract only. Transl. from Japanese.)
Water Turbidity Studies, Japan Water Turbidity Research Association 2(4):215-221.

The distribution of radionuclides in the substrate of the lake bed was studied from 1973-1975. The reference materials for analysis were the lake water, the freshwater fish (carp and crucian carp) and the substrate at the lake bottom. The concentrations of strontium-90 and cesium-137 in the substrate were examined. The relation between the vertical distribution and the amount of fall of strontium-90 and cesium-137 was observed. In addition, the accumulation rate of the substrate at the bottom of the lake was studied. The relation of the distribution of strontium-90 and cesium-137 was studied between the substrate and the fish and shellfish.

KEY WORDS: RADIONUCLIDES, FISH, SHELLFISH, JAPAN

Ottawa River Project Group. 1979.

MERCURY IN THE OTTAWA RIVER.
Environ. Res. 19:231-243.

The distribution and transport of mercury in a 3 mile section of the Ottawa River is described. The main soruce of mercury in this river is as a slimicide from a pulp processing plant. An exponential decay of Hg was observed with increasing distance from the plant. Mercury distribution was calculated over time: 1) water (1,300 kg/yr), 2) sediments (3.4 kg/yr), and suspended solids (290 kg/yr). Desorption of Hg from sediment to the water accounts for the low levels observed in sediments, according to the authors. About 1% of the total mercury in the system is in the methylated form. Plants can concentrate Hg up to 1,000X above water levels. Loss of Hg from plant detritus is slow. Biologically available Hg will decrease over time, with a half-life of 1-2 years. Fish which ingest methylmercury might also be able to eliminate it via an *in vivo* change to inorganic Hg, although no evidence is presented in the paper to that effect.

KEY WORDS: MERCURY, CANADA

Paasivirta, J., J. Sarkka, T. Leskijarvi, and A. Roos. 1980.

TRANSPORTATION AND ENRICHMENT OF CHLORINATED PHENOLIC COMPOUNDS IN DIFFERENT AQUATIC FOOD CHAINS.
Chemosphere 9:411-456.

Chlorinated phenols are manufactured for biocides and are also used as wood preservatives in sawmills. In all of the chlorinated phenols, degradation is slow. Tetrachloroguanicol is very poisonous to fish and has similar properties to mercury in that biomagnification occurs in the food chain. Trichlorophenol, tetrachlorophenol and trichloroguanicol biomagnify in the food chain like PCB's and DDT.

KEY WORDS: CHLORINATED HYDROCARBONS, BIOMAGNIFICATION, FINLAND, BIOCIDES

Pavlou, S.P., R.N. Dexter, W. Hom, A.J. Hafferty, and K.A. Krogslund. 1978.

AQUATIC DISPOSAL FIELD INVESTIGATIONS, DUWAMISH WATER DISPOSAL SITE, PUGET SOUND, WASHINGTON; APPENDIX E. RELEASE AND DISTRIBUTION OF POLYCHLORINATED BIPHENYLS INDUCED BY OPEN-WATER DREDGE DISPOSAL ACTIVITIES.
Tech. Rep. D-77-24. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 96 pp. + microfiche.

Using a grid system over a disposal site in the Duwamish Waterway in Puget Sound, Washington, the authors measured the PCB concentration in the sediment. Values of PCB in the sediment under the grid varied from 0.2 ppm to over 6 ppm. The authors were careful to correct for sample contamination bias during sampling and analysis. One duplicate set of samples was also analyzed by an outside agency with no significant differences in results.

Highest concentrations were found in the center of each station grid, with values diminishing from the center. An important finding of the study

BEST [illegible]

was that no significant reduction in PCB levels in the sediments occurred over time (approx. 9 months), which indicated that no resuspension of sediment or bedload transport had occurred. Also, except for a short time after disposal, the water column levels of PCB over disposal sites were not altered from ambient over the 9 month period. Though the addition of the contaminated sediment may have doubled previous PCB levels in the fill area, the authors maintain that with the present limited knowledge of the sediment dynamics of PCB, the ecosystem importance and ultimate effects of this increase cannot be predicted.

KEY WORDS: PCB, ESTUARIES, DREDGED MATERIAL, WASHINGTON

Pearce, J.B. 1972.

THE EFFECTS OF SOLID WASTE DISPOSAL ON BENTHIC COMMUNITIES IN THE NEW YORK BIGHT.
Pages 404-411 in M. Ruvio, ed. Marine Pollution and Sea Life. F.A.O.

Meio- and microfauna in uncontaminated sediments, dredge spoil, and sewage sludge were compared. Areas with much sewage sludge were devoid of animals. These areas contain much hydrogen sulfide, some petrochemicals and usually heavy metals. Around this area is a belt of sporadically impoverished ground. Increased organic matter in coarse sediments does not have an enriching effect on the associated fauna. Heavy metal contamination is as high or higher in dredged sediment as sludge. Also, there were significant levels of chlorinated hydrocarbons in the sediment.

Amphipods were almost completely absent from spoil and sludge disposal areas. Few live crabs were found in sludge areas. Those that were present exhibited extensive erosion of the exoskeletons. Dredge and sewage spoil areas were toxic to settling crab larvae and juvenile stages as well.

KEY WORDS: NEW YORK, DREDGING, SEWAGE SLUDGE, BENTHOS, DREDGED MATERIAL

Pearson, W.H., D.L. Woodruff, P.C. Sugarman, and B.L. Olla. 1981.

EFFECTS OF OILED SEDIMENTS ON PREDATION ON THE LITTLENECK CLAM, PROTOTHACA STAMINEA, BY THE DUNGENESS CRAB, CANCER MAGISTER.
Estuarine Coastal Shelf Sci. 13:445-454.

Field and laboratory experiments examined how oiled sediment influenced predation on littleneck clams, Protothaca staminea, by Dungeness crabs, Cancer magister. Prudhoe Bay crude oil was mixed with sediment until an approximate concentration of 10,000 ppm was attained. It was expected that this would fall to 10-20 of the nominal value when distributed to field cages, which would then be fairly representative of oil-polluted sediment. Throughout the experiments, composite cores were taken from each of the four experimental cages to determine the actual concentrations. A total of 320 clams of various size classes were used in eight cages (four experimental and four control) in a 13-day experiment, while 384 individuals were used in a 29-day experiment. One crab was added per cage and clam counts (dead, alive, shell fragments, depth of burial) were made every 2 to 4 days. In both experiments, crabs consumed more clams from oiled than from clean sand. Clams were buried shallower in oiled than in clean sand.

To test whether the observed increase in predation rate on clams from oiled sand was due to shallow burial, a 19-day laboratory experiment examined predation rates on clams buried in different depths of sand. The high consumption of clams from shallow-clean sand indicated that the shallow burial could have accounted for most but not all the higher consumption of clams in oiled sand. In a second laboratory experiment without crabs, clams were again shallower and also reburrowed slowly in oiled than in clean sand.

The authors make a very cogent point that changes in the rate of predation due to polluted sediment probably has as much validity in the reduction of benthic populations as does the toxic effect of a pollutant by itself.

KEY WORDS: HYDROCARBONS, PREDATION RATES, CLAM, CRAB, SHELLFISH, CRUSTACEAN

Peddicord, R.K. 1980.

DIRECT EFFECTS OF SUSPENDED SEDIMENTS ON AQUATIC ORGANISMS.
Pages 501-536 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 1. Ann Arbor Science, Ann Arbor, Mich.

Laboratory experiments are described which involved metals, chlorinated hydrocarbons, and other pollutants in contaminated sediments. Uncontaminated sediments were used as controls. Animals tested included two species of crab, *Crangon nigromaculata* and *Cancer magister*, one species of bivalve mollusk, *Mytilus californianus*, one ascidian, *Ascidia ceratodes*, and the American lobster, *Homerus americanus*. In three sets of flow-through aquaria (two control and six experimental), sediment was introduced at desired concentrations from a slurry proportioning system. The experiments were run for 25 days and 15-20 of each species were placed in each of the tanks. The water in the tanks was circulated to keep the particles in suspension but not, the author maintains, enough to disturb small test organisms. All aquaria were maintained at 33 ppt and at 10-12°C, with a D.O. of 7.5-8.0 ppm. Mortalities were recorded and afterward the survivors in contaminated sediment were analyzed for tissue content of the following: As, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn, chlordane, heptachlor, dieldrin, aldrin, endrin, DDT, DDD, DDE and PCB. However, it was not possible to tell which concentration was responsible for uptake, since analyses were made on samples of survivors pooled from all concentrations after 4 days post-exposure time in clean water.

The results varied with the kind of animal involved. For example, *C. nigromaculata* withstood all concentrations of uncontaminated sediment with no mortality, whereas *M. californianus* experienced 35% mortality by 21 days at a sediment concentration of 15.5 g/liter. The latter species also experienced almost total mortality in contaminated sediment at 3.0 g/liter. Unfortunately, not all species were tested in both uncontaminated and contaminated sediments. For example, *A. ceratodes* was tested only in contaminated sediment (where it experienced increasing mortalities with increasing sediment concentration). *Cancer magister* and *Homerus americanus* juveniles were tested in contaminated sediment, also. Most of the *C. magister* deaths during the experiments (i.e., 92% or 37 individuals) occurred during molting. On the contrary, no mortalities occurred in *H. americanus* juveniles at concentrations up to 20 g/liter, even though they, too, molted (29 molts observed).

The author concludes that the sediment exposure times and sediment concentrations necessary for death based on these experiments are "far above those likely to be created in the water column by just dredging and disposal operations." Long-term and sublethal effects, however, were not addressed.

KEY WORDS: SUSPENDED SEDIMENT, BENTHOS, METALS, PESTICIDES

Pentreath, R.J. 1976a.

THE ACCUMULATION OF MERCURY FROM FOOD BY THE PLAICE, PLEURONECTES PLATESSA L.
J. Exp. Mar. Biol. Ecol. 25:51-65.

Locally caught (i.e., coast of England) plaice, Pleuronectes platessa, were force-fed starch-gelatin capsules containing mercury-203 in the laboratory. Also, some individuals were fed mercury-203-labeled clamworms, Nereis diversicolor. Though some of the fish had to be force-fed the worms, others took them naturally. The labeling was in the inorganic $^{203}HgCl$ form, as well as the methylated $CH_3\ ^{203}HgCl$ form (separate groups). The short-term (5 day) rates of elimination of the compounds from the fish were measured as well as the accumulation in muscle and other tissues after 36 days.

In the short term experiments, it was found [illegible] an average of only 11.3% of the inorganic Hg remained in the fish after 5 d[illegible] hile the fish fed the methylmercury retained 89% of the compound. Much [illegible] methlymercury (about 80%) was associated with muscle. Based on the resea[illegible] others, the authors speculated that the methylmercury was probably conti[illegible] resorbed by the kidney, rather than being excreted. They also cite [illegible] ich indicate that plaice caught nearshore have higher mercury tissue [illegible] han specimens from more oceanic locations. The implication is that [illegible] bo[illegible]-feeding flatfish ingests sediment along with its prey, and if the sediment contains mercury, particularly in the methylated form, the fish tissue will reflect that fact.

KEY WORDS: MERCURY, FISH, BIOACCUMULATION, ENGLAND

Pentreath, R.J. 1976b.

THE ACCUMULATION OF MERCURY BY THE THORNBACK RAY, RAJA CLAVATA L.
J. Exp. Mar. Biol. Ecol. 25:131-140.

The thornback ray, Raja clavata, was the subject of bioaccumulation experiments using mercury-203-labeled clam worms, Nereis sp. Some of the rays were force-fed the worms; others ate them naturally. The mercury was divided into an inorganic form ($^{203}HgCl$) and an organic ($CH_3\ ^{203}HgCl$) form. The accumulation of the organic form of mercury was great. Over 90% of the labeled methylmercury was retained in the ray and most of that was located in muscle tissue. The author underscores the importance of this finding by indicating that the native Nereis sp. off the English coast where the fish were collected may contain up to 15 µg of organic mercury per gram of tissue. The worms are available as food in the natural environment for the ray. The author maintains that a total ray body content of about 1,100 µg Hg could be maintained by a low intake of just 2-3 µg Hg a day. However, the body burden of this fish, as with others, is complex and based on age, growth rate, diet, maintenance ratios and conversion efficiencies. Therefore, there are no easy correlations between laboratory and field observations.

KEY WORDS: MERCURY, FISH, BIOACCUMULATION, ENGLAND

BES[illegible]

Percy, J.A. 1977.

RESPONSES OF ARCTIC MARINE BENTHIC CRUSTACEANS TO SEDIMENTS CONTAMINATED WITH CRUDE OIL.
Environ. Pollut. 13:1-10.

Only the amphipod, *Onisimus affinus*, consistently and overwhelmingly rejected sediments contaminated with oil. Another amphipod and two isopods did not discriminate consistently. With increasing oil concentration, the ability of the animals to differentiate clean from contaminated sediment is impaired. Once oil is in the sediment, its rates of decomposition and oxidation are reduced. These rates are even lower in the subarctic.

KEY WORDS: OILS, CRUSTACEAN, ARCTIC, ALASKA

Pesch, C.E. 1979.

INFLUENCE OF THREE SEDIMENT TYPES ON COPPER TOXICITY TO THE POLYCHAETE, *NEANTHES ARENACEODENTATA*.
Mar. Biol. 52:237-245.

The importance of sediment type with regard to the effect of a heavy metal (Cu) on infauna--in this case a marine polychaete worm--is the subject of this research. The polychaete, *Neanthes arenaceodentata*, was subjected to flow-through laboratory LC_{50} experiments in which the subjects were divided into four groups: sand, mud, sand-mud mixture, and no sediment at all. The concentration of copper in solution was maintained at 0.10±0.015 mg/liter. Those animals without sediment experienced 50% mortality in 7.8 days, while the LC_{50} for the sand group was 36.5 days, the LC_{50} for the sand-mud group was 54.5 days and for mud alone, it was 50 days. It is obvious that the type of substrate affects the mortality response to copper, although the results here are blurred somewhat. The author readily admits that physiological stress in the no-sediment group may have been a factor in the early large mortality. Aside from that, the author postulates that the sediment affects mortality in two ways: 1) it causes time delay in the mortality response, and 2) it lowers the exposure concentration by binding to the pollutant, thus tying it up.

KEY WORDS: POLYCHAETE, COPPER

Pesch, C.E., and D. Morgan. 1978.

INFLUENCE OF SEDIMENT IN COPPER TOXICITY TESTS WITH THE POLYCHAETE, *NEANTHES ARENACEODENTATA*.
Water Res. 12:747-751.

This paper describes experiments to determine the effect of the presence of a substrate (sand) on the toxicity of Cu to a marine worm, *Neanthes arenaceodentata*. The animals were divided into groups. At each of five concentrations of Cu in seawater, two groups--sand and no substrate--of worms were subjected to 28 days under flow-through conditions. It was found that the presence of the sediment increased the time required to reach an LC_{50}. Statistics confirmed that all concentrations of Cu, the worms in sand were less affected. The author suggested further experiments using different sediments and different toxicants.

KEY WORDS: POLYCHAETE, COPPER

Petrocelli, S.R., and J.W. Anderson. 1976.

DISTRIBUTION AND TRANSLOCATION OF RESIDUES OF DIELDRIN--A CHLORINATED HYDROCARBON INSECTICIDE--AMONG WATER, SEDIMENTS AND ORGANISMS FROM SAN ANTONIO BAY. Pages 185-218 in A.H. Bouma, ed. Shell Dredging and Its Influence on Gulf Coast Environments.

Electron capture gas-liquid chromatography was used to analyze water, sediment and organisms for chlorinated hydrocarbon residues. Relatively low contamination levels (ppb) were found in the San Antonio Bay area.

Blue crabs had a greater incidence of contamination than other organisms tested (dieldrin, 32%; DDT's, 94%). High levels of DDT's in crabs may be because crabs eat many things containing DDT (fish, benthos, plants, and detritus). Oysters (dieldrin, 25%; DDT's, 60%) and clams (dieldrin, 31%; DDT's, 68%) were comparable, while penaeid shrimp had the lowest incidence of contamination (dieldrin, 25%; DDT's, 13%).

Lab experiments determined that San Antonio Bay sediments adsorb up to 80% of the dieldrin in sea water. Adsorption of dieldrin was inversely related to particle size and water holding capacity and may also be related to the polarity (symmetry) of the insecticide, organic content, and cation and base exchange capacity of sediments. Maximum sorbtion of DDT's and dieldrin to sediments occurs within 1 hour.

Bivalve mollusks accumulated dieldrin to 10-23% of concentrations in the sediment. Blue crabs fed Rangia cuneata contaminated with dieldrin had biomagnification factors up to 6.8.

KEY WORDS: BIOACCUMULATION, TEXAS, PESTICIDES, BIOMAGNIFICATION

Reish, D.J., T.J. Kauwling, A.J. Mearns, P.S. Oshida, S.S. Rossi, F.G. Wilkes, and M.J. Ray. 1978.

MARINE AND ESTUARINE POLLUTION.
J. Water Pollut. Control Fed. 50(6):1424-1469.

This is a review paper of 1976 and 1977 articles which consider the topic of marine and estuarine pollution. As part of their broad review, the authors mention papers which deal with the subject of sediment-biota interactions

KEY WORDS: REVIEW, ESTUARIES

Roesijadi, G., J.W. Anderson, and J.W. Blaylock. 1978.

UPTAKE OF HYDROCARBONS FROM MARINE SEDIMENTS CONTAMINATED WITH PRUDHOE BAY CRUDE OIL: INFLUENCE OF FEEDING TYPE OF TEST SPECIES AND AVAILABILITY OF POLYCYCLIC AROMATIC HYDROCARBONS.
J. Fish. Res. Board Can. 35:608-614.

Selected benthic animals were exposed to marine sediments contaminated with Prudhoe Bay crude oil in the laboratory. Uptake of aliphatic and diaromatic hydrocarbons by two deposit feeders, *Macoma inquinata* and *Phascolosoma agassizii*, was compared with a suspension feeder, *Protothaca staminea*. The deposit feeders generally accumulated hydrocarbons to a greater extent than the suspension feeder. After 40 days in the field there was no trace of hydrocarbons in the suspension feeder, but from .85-2.79 μg/g total hydrocarbons in the deposit feeders. Other factors also played a role in the extent of contamination. Hydrocarbon concentrations in the bivalve species increased during the 60 day exposure period, whereas concentrations in the sipunculid *P. agassizii* appeared to have reached equilibrium early in the exposure.

Compounds directly associated with sediment were less available for uptake than those released from sediment to the surrounding seawater. Concentration factors for sediment were ≤ 0.2; those for uptake from seawater were 10-1349. It is possible that hydrocarbons in interstitial water may be a prime source of contamination for intertidal species. Additionally, the heavier molecular weight aromatic compounds tended to be more concentrated in tissue and retained for longer periods of time than the lighter compounds.

KEY WORDS: BENTHOS, BIOACCUMULATION, OIL

Rubenstein, N.W., C.N. D'Asaro, C. Sommers, and F.C. Wilkes. 1980.

THE EFFECTS OF CONTAMINATED SEDIMENT ON REPRESENTATIVE ESTUARINE SPECIES AND DEVELOPING BENTHIC COMMUNITIES.
Pages 445-461 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 1. Ann Arbor Science, Ann Arbor, Mich.

To indicate the potential for sediment to contaminate the biota, the authors point out that in one recent year (1978) over 190 million cubic meters of dredged materials were deposited along the coasts of the United States. Experiments were set up in 10 gallon aquaria with flowing filtered seawater at the EPA laboratory in Gulf Breeze, Florida. The contaminant here was kepone in various concentrations (0.1, 1.0, and 10.0 mg/liter of seawater) which were mixed with clean silica sand (90% sand: 10% silt-clay). Experimental animals utilized were mysid shrimp (*Mysidopsis bahia*), oysters (*Crassostrea virginica*), and lugworms (*Arenicola cristata*). Three reps were run at each concentration along with controls. In addition to the artificially contaminated sediment, natural sediment from the kepone-contaminated James River (concentration=0.5-1.0 ppm) and from the Houston Ship Channel were also used. Each aquarium contained 10 mysids, 5 oysters, and 5 lugworms which were held for a period of 28 days.

The oysters showed significantly less (32% less at p=0.05) shell growth at 10 ppm and 1 ppm, but showed only a 6% decrease over controls at 0.1 ppm kepone. Neither oysters nor lugworms experienced mortality, however. The mysid shrimp, on the other hand, experienced mortality at all concentrations: 20% at 0.1 ppm, 30% at 1 ppm, and 37% at 10 ppm. The lugworms demonstrated complete inhibition of burrowing at 10 ppm kepone, whereas at 1 ppm and 0.1 ppm they did not differ in burrowing activity from controls. Both oysters and lugworms accumulated kepone in their tissues.

The James River sediment caused no mortality in any of the experimental animals, but it did cause a 45% shell growth decrease in oysters over the control group by the 4th week. Both oysters and lugworms accumulated kepone from this sediment. No significant difference between experimental and control animals was observed with the Houston Ship Channel sediment.

KEY WORDS: KEPONE, MYSID, OYSTERS, POLYCHAETES, CRUSTACEAN

Rutzler, K., and W. Sterrer. 1970.

OIL POLLUTION DAMAGE OBSERVED IN TROPICAL COMMUNITIES ALONG THE ATLANTIC SEABOARD OF PANAMA.
Bioscience 2:222-224.

Intertidal biota suffered most from oil spills. On rocky shores, a seawater-oil spray covered plants 2 m above the tide mark, many of which died. Supralittoral spray pools covered with oil were devoid of life. Exposure to sun was found to harden the oil, thus allowing repopulation of substrates.

Coral reefs were unaffected by oil, but this was probably due to the fact that they were submerged and so did not come in contact with any of the oil. On the sand beach, the surface layer looked clean, but the area was heavily oiled deeper in the sediment. A dramatic reduction of the meiofauna population was observed; the crustaceans were among the first mortalities.

The mangroves suffered most from the oil spill. Roots were covered with oil, completely clogging the pneumatophores of the black mangroves. The algae associated with mangroves and their associated microfauna were practically eliminated, as were most sedentary animals such as oysters, mussels and barnacles.

KEY WORDS: OILS, PANAMA

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980.

ANATOMY OF AN OIL SPILL: LONG-TERM EFFECTS FROM THE GROUNDING OF THE BARGE FLORIDA OFF WEST FALMOUTH, MASSACHUSETTS.
J. Mar. Res. 38(2):265-380.

This is a large and comprehensive article which concerns research done on the effects of an oil spill near Falmouth, Massachusetts, on estuarine and marine benthos. The barge, "Florida," spilled 650,000-700,000 liters of No. 2 fuel oil into Buzzard's Bay and the wind drove it into Wild River Harbor. The expressed purpose of the paper is ". . . to demonstrate more than adequately the persistent, deleterious effects of No. 2 fuel oil on marine benthos." Hence, the length and detail of the paper. Methodologies for biological, sedimentary, and chemical analyses are fairly standard. It should be pointed out, however, that the mesh size used for sieving the benthos was 0.297 mm, which is somewhat smaller than the 0.5 mm mesh which is more generally used in such studies. Data were approached in many ways: indices of diversity, evenness, and coefficients of variation were calculated; graphs of densities of dominant species over time were plotted; cluster analyses were performed.

Among the many findings of the study were that the intertidal and subtidal zones of the river demonstrated highest oil concentrations and slowest degradation rates. Further, Capitella capitata, an opportunistic polychaete, was the dominant species at the nearshore stations for almost a year after the spill; normal population composition was severely curtailed. Population recovery at nearshore stations began slowly and was not very far along even after 2.5 years. Biodegradation (through bacterial action) and dissolution were the chief means of oil degradation, but this progressed slowly and nearshore sediments were still leaching oil two or more years after the spill. The authors suggested that much is still unknown about this and other spills, particularly with regard to physiological and behavioral damage, and to marine trophic structure effects.

KEY WORDS: OILS, BENTHOS, ESTUARIES, MASSACHUSETTS

Sato, Y., and M. Minokawa. 1978.

MERCURY CONTENT OF FISH AND BOTTOM MUD FROM SANRIKU COASTAL WATERS IN THE NORTHEASTERN PART OF JAPAN. (Abstract only. Transl. from Japanese.)
Food Hyg. 19(4):357-363.

In preliminary studies, the mercury content of fish and bottom mud from five neighboring bays along the coast were comparatively studied. The results showed that the concentration of mercury was greatest in the Bay of Kamaishi. The authors collected rock trout of the same size in each bay. The comparison between the mean value of mercury content and the regression line of the estimated value of mercury per unit weight was carried out. The result indicated that the mercury content in the rock trout from the Bay of Kamaishi was the highest and that all of the rock trout were contaminated by mercury. The content of mercury was in proportion to the weight of fish and shellfish. The comparison between the mean value of mercury content of mackerel from Sanriku coastal waters and the regression line of the estimated value of mercury per weight was carried out on a seasonal basis. Both habitat of the mackerel and the high concentration of mercury along Sanriku coastal waters were studied.

KEY WORDS: MERCURY, FISH, SHELLFISH, JAPAN

Scarratt, D.J., and V. Zitko. 1972.

BUNKER C OIL IN SEDIMENTS AND BENTHIC ANIMALS FROM SHALLOW DEPTHS IN CHEDABUCTO BAY, N.S.
J. Fish. Res. Board Can. 29:1347-1350.

Soft sediments showed little evidence of diminution of Bunker C concentration in the 26 months following the wreck of the tanker "Arrow." Coarse sediment samples showed maximum oil concentrations about 1 year after the wreck and some reduction since then. No evidence was visible that subtidal animals died of oil exposure, even though some had been ingesting oil.

Herbivorous or browsing species had higher oil content than carnivorous or omnivorous species. Some carnivorous or omnivorous species are able to assimilate and partly metabolize Bunker C oil. There is no evidence that Bunker C is being concentrated in higher parts of the food chain.

KEY WORDS: OILS, CANADA, BIOACCUMULATION, BENTHOS

Schell, W.R., and R.L. Watters. 1975.

PLUTONIUM IN AQUEOUS SYSTEMS.
Health Phys. 29:589-597.

This paper is a review of the available information concerning plutonium in the aquatic environment. Pu levels are low and the data on its environmental concentrations are very limited. The distribution of sizes among colloidal Pu species influences the fate of the element in interactions with minerals or other suspended particles. Different oxidation states of Pu (+3, +4, +5, +6) vary with environmental conditions. Plutonium exists in the particulate, soluble, and colloidal states. The longer the mean residence time in the environment, the greater the potential buildup in pelagic organisms. Resuspension is a source to the environment as well as ingestion by benthic animals.

Plankton exhibits the highest concentration factors for plutonium, and these factors decrease with increasing complexity of the organism. Pu also decreases in concentration with increases in trophic level. Concentration factors for different types of organisms are: several thousand for algae; 760-1600X for benthos; 360±100X in zooplankton; 270±100X in bottom-feeding fish, 14-33X in planktivorous fish and 1.5-7X in piscivorous fish.

KEY WORDS: REVIEW, PLUTONIUM, METALS

Schnoor, J.L. 1981.

FATE AND TRANSPORT OF DIELDRIN IN CORALVILLE RESERVOIR: RESIDUES IN FISH AND WATER FOLLOWING A PESTICIDE BAN.
Science 211:840-842.

Laboratory and field studies showed that the dieldrin concentration in fish, sediments and the water column of the Coralville Reservoir, Iowa, has decreased by a factor of four since 1969 and 1970. Using these data, a mathematical model which considered sediment degradation rates, sorption rates, animal uptake, depuration, etc., was developed to stimulate the fate and transport of the pesticide. According to the model, in any one year, approximately 50% of the lost dieldrin is exported from the reservoir in the outflow, 40% undergoes sedimentation, and 10% enters the fish. Currently, the level in fish tissue is less than the 300 ppb "safe level" recommended by the FDA. The model predicts that levels in bottom-feeding fish will average less than 100 ppb by 1986. It remains to be seen whether the model will be useful in other contaminated bodies of water or with other pollutants.

KEY WORDS: DIELDRIN, IOWA, MODELLING

Schultz, D., and L.B. Tebo, Jr. 1975.

BOONE CREEK OIL SPILL.
Pages 583-588 in Conference on Prevention and Control of Oil Pollution.
American Petroleum Institute.

Approximately 7,000 gallons of No. 2 fuel oil spilled into Boone Creek. This study lasted for 6 months and for the entire time, there was an oil smell and oil sheen on the water. Hydrocarbons were still present in the sediments 13 months after the spill.

Samples of organisms from all stations had fewer taxa than the control site above the spill. Polychaetes and insect larvae (caddisfly, stonefly, and mayfly nymphs) were most abundant in March (the time of the spill). Mean numbers of individuals collected in substrate samples were 59 for the control area compared to 17 for the station closest to the spill, and 10 for the furthest station. By September (6 months later) a general increase in taxa was observed, indicating partial recovery by the stream benthos. Ninety percent of the standing crop of fish were killed by the spill. The paper divided the river's insect larvae into oil sensitive and oil tolerant groups. Fish, algae and periphyton levels were also monitored.

KEY WORDS: OILS, INSECTS, POLYCHAETE

Shaw, D.G., and J.N. Wiggs. 1980.

HYDROCARBONS IN THE INTERTIDAL ENVIRONMENT OF KACHEMAK BAY, ALASKA.
Mar. Pollut. Bull. 11:294-300.

A herbivorous limpet contained petroleum within its tissues. The limpet apparently ingests the petroleum as it eats, since the intertidal algae upon which it feeds have been shown to accumulate petroleum as a surface coating. In an area where both petroleum and coal are present, the filter-feeding mussel, Mytilus edulis, contained water-bourne petroleum hydrocarbons. The deposit-feeding clam, Macoma balthica, contained an array of hydrocarbons which suggested detrital coal as the source. Animals higher in the food web, including gastropods and urchins, showed no evidence of petroleum contamination.

KEY WORDS: HYDROCARBONS, MOLLUSKS, ALASKA, BIOACCUMULATION, BIOMAGNIFICATION, CLAM

Sheffy, T.B. 1978.

MERCURY BURDENS IN CRAYFISH FROM THE WISCONSIN RIVER.
Environ. Pollut. 17(3):219-225.

The first 100 km of the Wisconsin River, from its northern origin at the Wisconsin-Michigan border, is not industrialized. The next 600 km, down to its mouth at Prairie de Chien, where it meets the Mississippi River, supports 16 pulp and paper mills and 1 chlorine-caustic soda plant. Mercury, released during manufacturing processes, is usually found in sediments (as HgS) downstream of the plants. In an effort to get an indication of the presence of mercury in organisms, crayfish (Orconectes virilis) were collected at 34 stations, approximately equally spaced along the length of the river. Three animals were collected at each station and the amounts of Hg in their large abdominal muscles were measured. Values in the industrial zone were significantly higher than in those crayfish found in the upper, unpolluted 100 km of the river, where values were frequently below the detectable limit of 0.02 mg/kg (flameless atomic absorption spectrophotometry). The highest values (e.g., 0.56 mg/kg) were found at Petenwell Flowage, a large (15 km x 15 km) impoundment about 30 km downstream of the chlorine-caustic soda plant. In general, the most contaminated crayfish corresponded with high sediment Hg values. However, there were very low or undetectable levels within the lower portions of the river which this paper does not explain.

As the author points out, the crayfish is ubiquitous in distribution within the river, is restricted in its movements within an area, and is a bottom scavenger. As such, the crayfish appeared to be a useful indicator of the extent of mercury pollution in the river.

KEY WORDS: MERCURY, CRAYFISH, RIVERS, WISCONSIN, CRUSTACEAN

Sims, R.R., Jr., and B.J. Presley. 1976.

HEAVY METAL CONCENTRATIONS IN ORGANISMS FROM AN ACTIVELY DREDGED TEXAS BAY. Bull. Environ. Contam. Toxicol. 16(5):520-527.

Eighty individuals from three groups (mollusks, crustaceans and bony fishes) were collected from both dredged and undredged areas at 23 locations in San Antonio Bay. Previous research had shown that the sediment is low in heavy metal content. The area is far from industrial centers and apparently receives only minimal amounts of man-induced pollution. Tissue samples were wet-digested in the lab with a 2:1 mixture of nitric:perchloric acid. After drying and re-hydrating with distilled water, the material was analyzed via atomic absorption spectrometry. Modified methods were utilized to determine As and Hg.

The mollusks, *Crassostrea virginica* and *Rangia cuneata*, had the highest tissue concentrations of most metals. Unfortunately, only nine oysters and five *Rangia* were analyzed. Further, the paper does not indicate at which locations within the bay they were collected. The same applies to the crustaceans and the fish: small numbers and unlisted sample locations. However, the low levels of metals in these tissues do reflect the low levels in the bay sediment. In general, organisms from San Antonio Bay were lower in almost every metal than organisms from other unpolluted and/or minimally dredged areas. The fact that the area has been dredged many times over a 50-year period has apparently not affected the concentrations of metals in the organisms found there.

KEY WORDS: METALS, FISH, CRUSTACEAN, MOLLUSKS, TEXAS

Stout, V.F., and L.G. Lewis. 1977.

AQUATIC DISPOSAL FIELD INVESTIGATIONS, DUWAMISH WATERWAY DISPOSAL SITE, PUGET SOUND, WASHINGTON; APPENDIX B: ROLE OF DISPOSAL OF PCB-CONTAMINATED SEDIMENT IN THE ACCUMULATION OF PCB'S BY MARINE ANIMALS.
Tech. Rep. D-77-24. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 27 pp. + Append.

Five species of marine bottom dwellers were analyzed for tissue content of PCB's, having been obtained from the site of spoil placement from the Duwamish Waterway in Seattle, Washington. The sediment contained an average of 5.1 ppm of PCB's, as opposed to 2 ppm in nearby areas. The animals, *Parophrys vetulus* (English Sole), *Mytilus edulis* (mussel), *Pandalus borealis* (Alaska pink shrimp), *Pandalus platyceros* (spot shrimp) and *Parastichopus californicus* (sea cucumber), were sampled on a varying schedule, which doesn't allow for direct comparisons. However, the results indicated that uptake of

PCB's were minimal to low in all of the species examined. The authors concluded that the placement of a disposal site downstream from a polluted area introduces variables which cannot be controlled easily. They also suggested that the number of animals per sample should have been larger to achieve a statistically reliable value.

KEY WORDS: PCB, CRUSTACEAN, FISH, WASHINGTON

Swartz, R.C., and H. Lee, II. 1980.

BIOLOGICAL PROCESSES AFFECTING THE DISTRIBUTION OF POLLUTANTS IN MARINE SEDIMENTS. PART I. ACCUMULATION, TROPHIC TRANSFER, BIODEGRADATION AND MIGRATION. Pages 533-553 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

This comprehensive review paper concerns the biological processes which affect the biogeochemical cycling of contaminants. The authors cite papers dealing with bioaccumulation, trophic transfer, migration, biodegradation of oil and grease, pesticides, PCB's, and heavy metals. They point out that pollutants bind preferentially to different size classes of sediment and detrital particles and that it is often difficult to determine the availability of pollutants from sediment or the water column. Among those difficulties are: 1) differences among organisms in regulating their internal milieu; 2) utilization from sources, such as sediment and food; and 3) equilibrium conditions rarely exist among water, sediment and animals.

KEY WORDS: REVIEW, METALS, PCB, PESTICIDES, BIOACCUMULATION

Tatem, H.E. 1980.

EXPOSURE OF BENTHIC AND EPIBENTHIC ESTUARINE ANIMALS TO MERCURY AND CONTAMINATED SEDIMENT.
Pages 537-549 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 1. Ann Arbor Science, Ann Arbor, Mich.

Two experiments, unrelated except that they utilized the same animal stocks for bioassays, were conducted in the laboratory. The first experiment concerned the effect on the animals of adding a known quantity of $HgCl_2$ to test vessels. Controls were run simultaneously. The animals used were mysid shrimp, polychaetes and amphipods--10 of each in each vessel containing clean sediment and water (instant ocean at 25^{o}/oo). Concentration of $HgCl_2$ in test vessels was 10 ppb. Mortality at the end of the 15-day test period was significant (t-test; $p=0.05$) for mysids and amphipods. The second experiment utilized the same species as the first, *Mysidopsis bahia*, *Neanthes arenaceodentata*, and *Gammarus mucronatus*, plus another amphipod, *Haustorius* sp., to demonstrate the effect of known polluted sediment on biota. In this case, the polluted sediment was obtained from three areas of the Houston Ship Channel (HSCI, HSCII, and HSCIII). The set-ups, like the vessels in the first experiment, involved static conditions with frequent changes of water (here at 35^{o}/oo). As in the first experiment, the truly benthic organisms, *Neanthes* and *Haustorius*, were not as affected as the other species. At the $p=0.05$ level of significance, the mysids were significantly affected by all three of the ship channel sediments. The only other group of animals to experience significant mortality was Haustorius in HSI sediment.

The author points out the importance of statistical significance in the determination of mortality due to a given source. That is, control groups must be run simultaneously at each of the experimental conditions for each animal group tested.

KEY WORDS: MERCURY, BENTHOS

Taylor, T.L., and J.F. Karinen. 1977.

RESPONSE OF THE CLAM MACOMA BALTHICA (LINNAEUS), EXPOSED TO PRUDHOE BAY CRUDE OIL AS UNMIXED OIL, WATER-SOLUBLE FRACTION AND OIL-CONTAMINATED SEDIMENT IN THE LABORATORY.
Pages 229-237 in D.A. Wolfe, ed. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

Groups of adult clams in their natural sediment were exposed in flow-through aquaria to various concentrations of Prudhoe Bay crude oil on the mud surface, the water-soluble fraction of the oil and oil-treated sediment.

Reduced siphon activity in the presence of oil was the only sign of stress in the clams when oil was settled gently over the clam beds. Water-soluble and oil-treated sediment fractions of crude oil inhibited burrowing and caused clams to move to the sediment surface. Clam responses were directly proportional to oil fraction concentrations. With the water-soluble fraction, there was no mortality in 10 days of exposure, though some clams did surface. A concentration of 0.367 ppm of naphthalene was required to force 50% of the clams to surface in 3 days. In the oil-treated sediments, 0.67 g oil/cm^2 was required to get a 50% surfacing in 1 day. Some delayed mortality was observed after exposure for 30 days.

Although there were few deaths directly related to oil exposure, the clams' behavioral responses may be of great importance to their survival. Most of the surface clams recovered, but in nature clams that come to the sediment surface may be eaten by predators or die from exposure. The oil may have a narcotic effect on the nervous system or exposure to the oil stimulates the clam to close up.

KEY WORDS: OILS, CLAM, SHELLFISH

Teeny, F.M., and A.S. Hall. 1977.

AQUATIC DISPOSAL FIELD INVESTIGATIONS, DUWAMISH WATERWAY DISPOSAL SITE, PUGET SOUND, WASHINGTON; APPENDIX C: EFFECTS OF DREDGED MATERIAL DISPOSAL ON THE CONCENTRATION OF MERCURY AND CHROMIUM IN SEVERAL SPECIES OF MARINE ANIMALS.
Tech. Rep. D-77-24. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 22 pp.

This research involved determination of the effect on certain organisms of dumping Duwamish River material into Elliot Bay. The Duwamish River empties into Seattle Harbor and carries with it contaminants, particularly Hg and Cr, from several factories and shipyards. Animals chosen for in situ study included the sea cucumber, Parastichopus californicus, the mussel, Mytilus edulis, English sole, Parophrys vetulus, and three shrimps, the spot, Alaska pink, and the Oregon pink (Pandalus platyceros, P. borealis, and P. jordani, respectively). The methodology varied, however, for each of the animals studied. For example, spot shrimp were held in wire cages for 3 days during disposal, then sacrificed and analyzed. Sea cucumbers and mussels were held for 1, 2, and 3 weeks after disposal. Soles were collected just before and 2 weeks after disposal. Alaska pink shrimp were collected before and 2, 5, 14, 27, and 39 weeks after disposal and Oregon pink shrimp were collected at 5, 27, and 39 weeks but from the reference site only. It would be difficult to draw any comparative conclusions from this diverse methodology. However, the data are presented and compared and appear to be valid at least within species. The authors concluded that there was no effect on the animals due to placement of the dredged material. Also the levels of Cr and Hg decreased with time and exhibited seasonal variations. The data were in agreement with other research in the Puget Sound area.

KEY WORDS: CHROMIUM, MERCURY, BENTHOS, WASHINGTON, DREDGED MATERIAL

Thomas, M.L.H. 1973.

EFFECTS OF BUNKER C OIL ON INTERTIDAL AND LAGOONAL BIOTA IN CHEDABUCTO BAY, NOVA SCOTIA.
J. Fish. Res. Board Can. 30:83-90.

A large spill of Bunker C oil occurred in Chedabucto Bay, Nova Scotia, in February, 1970. On exposed shores, oil decreased steadily after oil stopped coming ashore. In sheltered areas, heavy oil contamination remained. Oil is deposited in heavy layers that adhere to rock, ice and algae. Crude oil forms a thin skin and becomes a stable surface. Reoiling was still occurring 2 years later when the skin on the oil softened in the summer, thus adding a chronic aspect to the problem.

The author found that the oil on rocky shores disappears quickly with very little harm to the biota. Initial effects of oil involved minor smothering of fauna and tearing loose of algae. An absence of snails indicated that the oil kills or stuns them, after which they are washed away. Longer term effects involved extensive mortalities among the clam, Mya arenaria, the alga, Fucus spiralis, and the marsh grass, Spartina alterniflora. Spartina can apparently withstand one oiling, but dies if exposed repeatedly.

KEY WORDS: OILS, MARSH, CLAM, CANADA, MOLLUSKS

Thomas, M.L.H. 1977.

LONG TERM EFFECTS OF BUNKER C OIL IN THE INTERTIDAL ZONE.
Pages 238-245 in D.A. Wolfe, ed. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

This article is a followup to the earlier Thomas (1973) paper. During the 6-year period of this study, mortalities of common species of all major communities have occurred. Although the entire intertidal area was exposed to the oil, none settled on the lower 1/4-1/3 of the tidal range and the oil that did settle higher had been dissipated from the lower tide levels first.

Some oil effects still persist in higher intertidal areas. Delayed recolonization in these areas is attributed to long-term toxicity. In the salt marsh, salt marsh cord grass was not initially affected by the oil since the spill occurred in the winter when there was no growth. Serious effects occurred later because of reoiling during the growing season, the grass requiring 2 years to begin recovery. Soft shell clams (*Mya arenaria*) have shown mortalities proportional to oil content of sediments--apparently due to synergistic effects of low food levels and high oil toxicity.
KEY WORDS: OILS, CANADA, GRASS, CLAM, MOLLUSKS

Thomas, M.L.H. 1978.

COMPARISON OF OILED AND UNOILED INTERTIDAL COMMUNITIES IN CHEDABUCTO BAY, NOVA SCOTIA.
J. Fish. Res. Board Can. 35:707-716.

A 4 mm mesh was used for biomass determination. Of 71 species found, 14 were unique to control and 9 to oiled locations. Diversity was uniformly higher at control than oiled stations. No difference in horizontal zonation was apparent. Analysis of abundance and biomass showed a significant overall difference between oiled and control situations. Ten species accounted for most of the variance between oiled and control stations. Six of these were more important at controls and 4 more important at oiled stations. The flora were particularly affected at oiled stations. Reductions in abundance, biomass and distribution were found in several major primary producers at all but the lowest tidal levels. With salt marsh cord grass, mortality from initial oiling may be delayed up to several years. Length and weight data for the clam, *Mya arenaria*, showed significantly lower values at oiled stations, but the periwinkle, *Littorina littorea*, showed the opposite effect due to trophic changes. On rocky shores, cleanup measures may not hasten recovery and might even delay it since the physical methods used to remove the oil harm the biota as well.
KEY WORDS: OILS, CANADA, MOLLUSKS, CLAM

Thompson, H.C., R.N. Farragut, and M.H. Thompson. 1977.

RELATIONSHIP OF SCARLET PRAWNS (*PLESIOPENAEUS EDWARSIANUS*) TO A BENTHIC OIL DEPOSIT OFF THE NORTH-WEST COAST OF ARUBA, CUTCH WEST INDIES.
Environ. Pollut. 13:239-253.

Oil was found in lumps on bottom sediments in relatively deep water (457-777 m). The three stations where the most prawns were caught were also the three oiliest. Scarlet prawns were found to be three times more abundant in oily areas than in unoiled areas. It was hypothesized that the prawns were attracted to the oil by the release of some chemical form, possibly via bacterial action. The oil found in this experiment did not consist of the usual isoprenoid hydrocarbons, but rather some unusual n-parafin hydrocarbons (n-C_{22}, n-C_{25}, n-C_{28}, n-C_{31}, n-C_{34}). Prawns from oiled and unoiled areas both had these unusual parafins in their bodies; however, prawns from oiled areas had much higher concentrations. The author hypothesizes some metabolic usage for these n-parafins.
KEY WORDS: OILS, WEST INDIES, CRUSTACEAN

Tietjen, J.H. 1977.

POPULATION DISTRIBUTION AND STRUCTURE OF THE FREE-LIVING NEMATODES OF LONG ISLAND SOUND.
Mar. Biol. 43:123-136.

Cores of 2.5 cm diameter were taken from grab samples of sediment in Long Island Sound. Quantitative and qualitative aspects of nematode population structure were examined in relation to environmental impact, indicated by large differences in heavy metals and organic carbon concentrations in the samples. Within each sediment type no differences existed between heavily affected and apparently non-affected sediments. These findings cast doubt on the use of heavy metal and organic carbon concentrations as indicators of environmental stress in nematodes, the use of diversity indices alone as indicators of environmental deterioration, etc. The author further questions the usefulness of field monitoring studies alone for the assessment of pollution impact on marine nematodes. In this paper, however, the author did not take other aspects, such as faunal similarity, comparability of sites, etc., into consideration when determining the value of field studies. Also, the paper addresses only nematodes, which may respond differently than other groups of animals.

KEY WORDS: HEAVY METALS, NEMATODE, BIOACCUMULATION, NEW YORK

Tietjen, J.H. 1980.

POPULATION STRUCTURE AND SPECIES COMPOSITION OF THE FREE-LIVING NEMATODES INHABITING SANDS OF THE NEW YORK BIGHT APEX.
Estuarine Coastal Mar. Sci. 10:61-73.

There were no significant differences in the density of nematodes associated with sediment type, organic carbon content, or heavy metal concentrations. However, a shift in species dominance occurred. In medium sands with low organic carbon and low heavy metal content, nematode fauna was characterized by dominance by members of the families Chromadoridae and Desmodoridae, low relative abundance of the family Comesomatidae and high species diversity. In silty sands or sand with high organic carbon or heavy metal content, fauna was characterized by low relative abundance of Chromadoridae and Desmodoridae, high dominance by Comesomatidae and low species diversity. Species diversity was inversely correlated with increased concentrations of Cd, Cu, Pb and Zn in medium sand but not in silty sand. This change in fauna was attributed to the comesomatid's ability to withstand stress much better than the others. However, the argument may be somewhat weakened, since the sampling precision of the study was admitted to be ±50%.

KEY WORDS: HEAVY METALS, NEMATODE, BIOACCUMULATION, NEW YORK

Tsai, C., J. Welch, K. Chang, J. Shaeffer, and L.E. Cronin. 1979.

BIOASSAY OF BALTIMORE HARBOR SEDIMENTS.
Estuaries 2(3):141-153.

Enough sediment was put into a tank so that when the tank was mixed thoroughly, the water was "black" (a somewhat unrealistic concentration). Acclimated fish (*Fundulus heteroclitus* and *Leiostomus xanthurus*) and a mollusk (*Mya arenaria*) were exposed in these static systems to a series of concentrations of suspended sediment from a number of stations and to suspensions of Fuller's earth in control tanks for 48 hours. The sediment was analyzed for the metals As, Cr, Pb and Zn. Also, PCB concentrations were determined. At lower concentrations of suspended solids, toxicant released from the sediment was proportional to the concentration of suspended solids. The Baltimore Harbor sediments were categorized into highly toxic, moderately toxic, low toxic and slightly toxic zones by comparing *Fundulus* 24 hr TL_m values with benthic species diversity. The authors determined that gross toxicity of sediments determined by bioassay can be used as an index of the suitability of the sediments for benthic macroinvertebrate communities.

KEY WORDS: METALS, FISH, MOLLUSKS, MARYLAND

Tuncel, G., G. Ramelow, and T.I. Balkas. 1980.

MERCURY IN WATER, ORGANISMS AND SEDIMENTS FROM A SECTION OF THE TURKISH MEDITERRANEAN COAST.
Mar. Pollut. Bull. 11:18-22.

Sediment samples were taken at four nearshore stations off the Turkish coast in the eastern Mediterranean Sea for analysis of the mercury content. These were correlated with water samples and trawl samples (seven species of fish and one species of shrimp) collected from the same general area. The water column values showed low amounts of Hg. Although one location, the Port of Mersin, was 2-3X higher than other water column stations, it was still comparable to other Mediterranean values. Likewise, Hg values in fish and shrimp tissue were low. For example, the shrimp, *Penaeus kerathurus*, had a mean tissue concentration of 20 µg Hg/kg wet tissue; the fish, *Mugil auratus*, also had a mean concentration of 20 µg/kg. Other species of fish averaged as high as 120 µg/kg and as low as 3 µg/kg. The authors indicate that these values are low in comparison to other Mediterranean areas and considerably lower than off the coast of Israel.

Except for the harbor sediments at Mersin, which contained averages of 0.44 µg Hg/g sediment and 0.48 µg/g sediment, the concentrations at other sampling sites were low, averaging from 0.019 µg/g to 0.058 µg/g. The authors concluded that their data point out the relatively unpolluted nature of the eastern Mediterranean and that sediment concentrations off Mersin are indicative of the effects of man's activities.

KEY WORDS: MERCURY, MEDITERRANEAN SEA, FISH, CRUSTACEAN, TURKEY

Ueda, Y. 1981.

DISTRIBUTION, ACCUMULATION AND SHIFT OF COBALT-60 IN THE BAY OF URASUKO, PARTICULARLY CENTERING ON THE GULFWEED. (Abstract only. Transl. from Japanese.)
Ecol. Chem. 4(3):15-21.

This article provides some information on the distribution, accumulation and shift of [illegible] released along the [illegible]. [illegible] gathered on the radionuclide cobalt-60 in the Bay of Urasoko located in the western part of Tsuruga Bay. Furthermore, the article provides general observations on various radioactive nuclides returned to the human body by eating marine products. The radionuclides were mixed and spread by the tide, precipitated and adsorbed by the sediment, or ingested by the fauna. Further, the radionuclides were taken up by plants. Gulfweed was particularly chosen as a subject of this research because its coefficient of concentration was found to be very high.

KEY WORDS: RADIONUCLIDES, COBALT, PLANTS, JAPAN

VanHassel, J.H., J.J. Ney, and D.L. Garling, Jr. 1980.

HEAVY METALS IN A STREAM ECOSYSTEM AT SITES NEAR HIGHWAYS.
Trans. Am. Fish. Soc. 109:636-643.

Sediment concentrations of lead, nickel and zinc were highly correlated with traffic density. Stream sediments along highways serve as a storage reservoir and as a primary source for bioaccumulation of heavy metals. The hardened exoskeletons of invertebrates also serve as sinks for heavy metals. However, in these studies, trophic level biomagnification was not evident. Lead concentrations in members of three benthic insect families were correlated with traffic density as were lead and zinc concentrations in three fish species. Seasonal variation was noted only in the maximum spring runoff period.

KEY WORDS: METALS, INSECTS, FISH, HIGHWAY

Varanasi, V., and D.J. Gmur. 1981.

HYDROCARBONS AND METABOLITES IN ENGLISH SOLE (*PAROPHRYS VETULUS*) EXPOSED SIMULTANEOUSLY TO (HYDROGEN-3) BENZO(A) PYRENE AND (CARBON-14) NAPHTHALENE IN OIL-CONTAMINATED SEDIMENT.
Aquat. Toxicol. 1:49-67.

English sole, *Parophyrs vetulus*, were exposed to [3H[benzo[a] pyrene (B[a]P) and carbon-14 naphthalene (NPH) in sediment containing 1% Prudhoe Bay crude oil. Bioconcentration values for NPH were greater than corresponding values for B[a]P in tissues of fish exposed for 24 hours. Between 24 to 168 hours after exposure, a substantial increase in B[a]P derived radioactivity occurred.

Fish metabolized B[a]P in the liver and transported the products to the bile. NPH is not stored in the body, but excreted prior to metabolism via gills and skin mucus. Therefore, examination of tissues to determine organismal exposure to compounds can be misleading due to differing rates of metabolism.

KEY WORDS: HYDROCARBONS, FISH

Varanasi, U., J.E. Stein, and T. Hom. 1981.

COVALENT BINDING OF BENZO(A) PYRENE TO DNA IN FISH LIVERS.
Biochem. Biophys. Res. Commun. 103(2):780-787.

BEST [illegible]

English sole (*Parophrys vetulus*) were force-fed capsules of tritiated benzo(a) pyrene in corn oil. The hydrocarbon became bound to the hepatic DNA and a binding index was calculated. The values for English sole liver DNA were of the same order of magnitude as those in mouse skin and mammary gland in which benzo(a) pyrene is carcinogenic. The authors were very cautious, however, in claiming that benzo(a) pyrene is carcinogenic to fish at the same levels as it is in the mouse. Though the methodology might seem unapplicable to the real world, it is stated that the animals do encounter this chemical and other polynuclear aromatic hydrocarbons in their environment. The implication is that they may ingest contaminated sediment while feeding.

KEY WORDS: HYDROCARBONS, FISH

Weimer, W.C., J.C. Laul, and J.C. Kutt. 1980.

PREDICTION OF THE ULTIMATE BIOLOGICAL AVAILABILITY OF TRANSURANIUM ELEMENTS IN THE ENVIRONMENT.
Pages 465-484 *in* R.A. Baker, ed. Contaminants and Sediments. Vol. 2. Ann Arbor Science, Ann Arbor, Mich.

There are few data on the long-term behavior of transuranium elements after they have weathered and reached equilibrium in the environment, which could take hundreds of years. Therefore, this research involved approximating that behavior using selected elements which have similar properties to the transuranium elements. The analogs were chosen on the basis of oxidation states, solubility products, hydrolysis constants, etc. The transuranium elements of interest to the researchers were plutonium, americium and curium (Pu, Am, and Cm). The analogs chosen and their oxidation states were Th+4 (thorium) for Pu+4; U+6 (uranium) for Pu+6; Nd+3 (neodymium) for Am+3; and Nd+3 for Cm+3. The bulk of the work, however, was done using the latter two groups.

To test whether these analog pairs indeed acted similarly, short-term studies were done on the uptake of both the element and its analog in plants (cheatgrass and snap beans) in the laboratory. The results were not significantly different between analog pairs. Soil samples from locations in the U.S. were also analyzed chemically for the analogs. It was found that soils with significant clay and organic matter may retain a greater fraction of weathered Nd. This fraction may comprise the principal constituents available to the biota.

The authors concluded that, in the short-term studies, the Am-Nd analogs acted nearly identically in the lab, as did the Ci-Nd analogs. Therefore, the ultimate biological availability of the transuranium elements Am and Ci in the environment can be predicted by the availability of isotopically exchangeable Nd in soils.

KEY WORDS: RADIONUCLIDES, BIOAVAILABILITY, PLANTS

Woodin, S.A., C.F. Nyblade, and F.S. Chia. 1972.

EFFECT OF A DIESEL OIL SPILL ON INVERTEBRATES.
Mar. Pollut. Bull. 3(9):139-142.

Number 2 diesel fuel was found to be highly toxic and persisted in patchy concentrations in the sediment for 6 months. The fuel, as it landed intertidally,

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caused mortality in many taxa. Some taxa, however, were not affected (Polychaeta: Capitellidae, Oweniidae; Molluska: *Crassostrea gigas*, *Mytilus edulis*, *Littorina* spp. and *Thais* spp.). *Thais*, though apparently dying when exposed to diesel fuel, recovers quickly when placed in clean water. No mortality of subtidal flora and fauna was observed. Larval recruitment was observed within 6 months.

KEY WORDS: OILS, INVERTEBRATES, WASHINGTON

Wormald, A.P. 1976.

EFFECTS OF A SPILL OF MARINE DIESEL OIL IN THE MEIOFAUNA OF A SANDY BEACH AT PICNIC BAY, HONG KONG.
Environ. Pollut. 11:117-130.

The diesel fuel spilled was especially toxic due to high concentrations of sulfur and aromatics. Meiofauna are sensitive indices of ecological health of a beach so, not surprisingly, the Picnic Bay meiofauna was almost totally destroyed 4 days after the spill. A few nematodes reappeared within 1 month of the spill. By the 5th month, 50-75% of the aromatics had evaporated and the entire sediment had gone anaerobic because of bacterial degradation of the oil. Meiofauna did not live deeper than 1 cm in the sediment for the first 7 months, until the oil content decreased by 50%. Shortly after this, the habitable zone deepened, and the harpacticoids returned. The high meiofaunal fluctuations observed 10 months after the spill were attributed to succession of meiofauna and predation by incoming meiofauna. Normal populations were reestablished by the next month.

The toxic aromatic fraction in the oil--not the total oil concentration--controlled meiofaunal reappearance. Heavy rains tend to flush the oil from the beach and so enhance recolonization. Though biodegradation is generally agreed to be oxygen-dependent, in anaerobic areas it becomes dependent on NO_3 and PO_4 levels. The author concludes that physical dispersion, not biodegradation, is the major component in cleaning sediments.

KEY WORDS: OILS, MEIOFAUNA, HONG KONG

Yasuno, T., S. Ogino, A. Ono, T. Ohata, and H. Ando. 1980.

MICROELEMENTS IN SHORT-NECKED CLAMS IN THE BAY OF TOKYO. II. (Abstract only. Transl. from Japanese.)
Pages 185-189 *in* Tokyo Metropolitan Hygiene Research Institute Annual Report, No. 31-1.

The authors measured all elements, including heavy metals, at five locations in the Bay of Tokyo. The relation between the distribution and amounts of elements in the substrate and the edible parts was studied at each location. The amounts of Hg and Mg in the shell did not indicate any significant differences due to the site of the collection. The amounts of Cd, Cr, Pb, Cu, Zn, Mn, Fe, and Sr were high in the western section of the bay and low in the eastern section of the bay. The amount of arsenic was low in the deep area of the bay, Chiba, and high on both sides of Chiba. The distribution trend was similar to the trend in the substrate. Shells and edible parts showed a weak positive correlation with As and Cu.

KEY WORDS: MOLLUSKS, HEAVY METALS, JAPAN

Yevich, P.P., and C.A. Barzcz. 1977.

NEOPLASIA IN SOFT-SHELL CLAMS (MYA ARENARIA) COLLECTED FROM OIL-IMPACTED SITES.
Ann. N.Y. Acad. Sci. 298:409-426.

Neoplasms were found in a maximum of 8% of all clams examined. Neoplasms occurred in the gonads and then spread by either:

1. Invasion through walls of follicles into visceral and connective tissues
2. Neoplastic cells can be shed from follicles and released via the genital pore into the epibranchial chambers, water tubes and ostia of the gills
3. Via the sinuses and blood vessels in the visceral mass to other body organs.

There was no relationship between sex or stage of sexual development of the animal and presence of neoplastic cells. Also, there was no relation between size or age and neoplastic development. Neoplasms were not associated with seasonal or cyclic changes. Neoplasms are probably the result of some change in the animals' environment--though not necessarily the oil.

KEY WORDS: OILS, CLAM, NEOPLASIA, SHELLFISH

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16. Abstract (Limit: 200 words)

A review and annotated bibliography of selected literature about the effects of contaminated sediment on the biota are presented. Pollution categories that are covered include heavy metals, hydrocarbons, synthetic organic compounds, and radionuclides. Under each category the following subjects are discussed where applicable: (1) availability to organisms, (2) biological effects, (3) types of plants and animals affected and during which life stages, if known, (4) bioaccumulation, (5) food web influences, and (6) major locations of known sediment contamination.

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